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Cognitive Tools for Facilitating Meaningful Interactions in Complex Domains

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A primary driver for pursuing the development of technology based adaptive tutoring is an attempt to replicate the effects of one-to-one tutoring with human tutors (Bloom, 1984). This paper situates the discussion of adaptive tutoring in the context of a theory-driven approach to the design of specific cognitive tools. Different methods exist to model individual differences in learning and performance as a precursor to adaptive tutoring (Lajoie, 2007). This paper describes how students interact with technology to solve medical problems and how they learn through interactions with simulated patient cases. Specific examples of medical models are provided that guide the design of technology enriched learning environment, including expert models, models of medical teams, and models of the culture of medicine.

Keywords: Cognitive Tools, Medical Problem Solving, Learning Trajectories.

COGNITIVE TOOLS FOR FACILITATING MEANINGFUL INTERACTIONS IN COMPLEX DOMAINS

The development of adaptive tutoring systems falls under the larger discussion of technology rich learning environments (TRE) that are designed for an instructional purpose to support the learner in achieving the goals of instruction (Lajoie & Azevedo, 2006). The role of the teacher and the learner will depend on both the purpose of instruction and the theory guiding the design of the TRE. Technologi-

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cal advances in teaching and learning environments should be designed based on a theory or model of learning and instruction. TREs should then be validated with learners and data collected to see whether or not the TREs meet the needs of learners. Having both theory and data iteratively guide the design and re-design process provides an impetus for increasing the effectiveness of TREs as teaching and learning environments.

Technology is a tool, a means to an end. Tools are designed for a purpose, and their effectiveness can only be assessed within the context of a purpose. The metaphor of computers as cognitive tools has been used to describe how technological tools can guide learners in accomplishing cognitive tasks (Jonassen, 1995; Jonassen & Reeves, 1996; Lajoie & Derry, 1993; Lajoie, 2000; Salomon, Perkins, & Globerson, 1991). In this paper I describe how the field of cognitive tools has changed over the last 2 decades in terms of the driving questions that guide researchers interested in the use of technology for teaching and learning. These driving questions are then analyzed in the context of the design of cognitive tools for medicine. Two contexts are described, one in internal medicine, where the focus is on the individual, and the second in emergency medicine where the emphasis is on team performance. The role of emotion, culture and assessment in these contexts is also discussed.

THEORY-DRIVEN DESIGN OF TECHNOLOGY RICH LEARNING ENVIRONMENTS

Technology needs to be designed to support, transform or extend learning for specific situations (Lajoie, 2007). When technological designs are driven by theories of learning and teaching, technology can empower students. Given the need to facilitate individual movement along a progressive learning trajectory (Lajoie, 2003), the expertise literature illustrates useful findings and methodologies that can contribute to the identification of proficiency and the cognitive components that differentiate between different levels of performance (see, for example, Chi, Glaser, & Farr, 1988; Ericsson, 2002).

Identification of proficiency differences is a first step to developing appropriate forms of scaffolding for the less proficient. Scaffolding can be defined as helping novices perform a task that they might not be able to perform without assistance, until they can do it on their own (Wood, Bruner, & Ross, 1976). Determining what to scaffold, when to scaffold, how to scaffold, and when to fade scaffolding are core questions that intersect with the identification of proficiency in specific contexts (Lajoie, 2005). Another important issue is who or what does the scaffolding: human teachers, tutors or peers, computers, or a combination of such elements. By definition, a scaffold is a temporary device meant to assist in accomplishing a task. Eventually, learners need to be independent in their pursuits. Consequently, the development of metacognition, or thinking about thinking (Flavell, 1979), is crucial to success. Theories of self-regulated learning pertain to specific contexts of how learners must become aware of what to monitor or pay attention to in order to achieve their potential in specific domains (Zimmerman, 1989). Thus, theories of self-regulation are a driving influence in designing computers as cognitive tools (Azevedo, 2005).

Another driving influence is the *cognitive apprenticeship* model (Brown, Collins & Duguid, 1989; Collins, Brown, & Newman, 1989). This model integrates theories of expertise, scaffolding, and self-regulation and provides a template for connecting abstract and real world knowledge by creating new forms of pedagogy based on a model of learners, the task, and the situation in which learning occurs.

COMPUTERS AS COGNITIVE TOOLS: QUESTIONS, ANSWERS AND MORE QUESTIONS

This section presents a discussion of the guiding questions that have driven researchers interested in the computers as cognitive tools theme over the last 2 decades and where the next decade may lead in terms of new questions.

To Model or Not to Model?

In an edited volume on computers as cognitive tools, Derry and Lajoie (1993) referred to 3 camps of researchers in the early 1990s who were exploring advanced uses of technology for teaching and learning. The camps consisted of those who modeled human learning and performance and implemented such models in intelligent tutoring systems that, through model tracing, could diagnose and then adapt to individual differences. The second camp were the non-modellers who stated that it was impossible to model human learning and performance and thus chose not to have the computer diagnose errors but rather envisioned the use of technology as a cognitive tool that situated experiences for learners in authentic contexts where technology supports the social experience that serves to scaffold learners. Finally, there was a middle camp that saw a place for combining cognitive apprenticeship, constructivist learning, and computer-based cognitive tools with computer-based student modeling (see, for example, Alessi, 2000; Spector, 2006). This group of researchers continues to adhere to the belief that computers can and should serve part of the cognitive mentorship function without giving over total control of the learning and assessment process to those using the system. In summary, the driving question at that time was: to model or not to model?

Who or What Should Do the Modelling?

The second volume of computers as cognitive tools (Lajoie, 2000) was intended to break the distance between the three camps of researchers and hence was subtitled "No More Walls." In particular, it focused on learning paradigm shifts that were guiding the design of computers as cognitive tools. Three guiding paradigms were highlighted: information processing, constructivism, and situativity, and reviewed with respect to how designers incorporated theories into the design of computers as cognitive tools. Researchers demonstrated the value in modeling both individual knowledge construction and learning in social situations through the use of technology. In this regard, broader notions of modeling were considered including both individuals and groups. Computer tutors, human tutors, and peers were considered as assisting in the modeling and consequently the new guiding question was: who or what should do the modeling? New cognitive tools were designed with multiple forms of knowledge representation and demonstrations were provided of how such representations could be used for assessment purposes. Once again, technology was at an advantage due to its ability to offer multimodal representations.

What to Model? The Intersection of Heart and Mind

A decade later, researchers are now facing different questions. Perhaps the most complex question pertains to modeling both the affective and cognitive aspects of learning and finding ways to engage learners in a world that requires adaptivity to new and challenging information that is presented at a rapid pace with demands for multiprocessing and quick turn-around. In addressing the affective component of learning, we need to remain focused on how affect influences decision-making and how we can keep individuals engaged as they interact with new technologies (Halverson & Collins, 2006). Malone and Lepper (1987) raised the issue of learner curiosity, intrinsic motivation, interest and challenge as key aspects influencing learner outcomes and Lepper (1988) cautioned that cognitive psychology start considering more affective factors. Snow (1989) broadened his definition of aptitude treatment interactions to consider the conative or volitional aspects of learning, or what drives learners to learn. Computers as cognitive tools need to model the intersection of heart and mind more closely in order to move the field of teaching and learning forward. The following section describes a range of approaches to designing computers as cognitive tools for medicine.

MEDICAL MODELS

As stated above, a theory driven approach to designing computer based learning approaches is needed and the theory must fit the situation. The first situation described here contextualizes the teaching of diagnostic reasoning to third year students in internal medicine, with an emphasis on the individual learner's performance using Bioworld, a computer based learning environment. The second situation concerns teaching students issues pertaining to emergency medicine, which involves modeling the team or group roles and how that influences patient management. The importance of models are described in these 2 contexts along with an introduction to the importance of "new models" that examine the role of affect, emotion, and culture in the context of decision making.

The Learning Trajectory and the Role of Expert Models

For the last several years, we have been exploring how medical personnel diagnose patient problems. BioWorld is designed to support different learning trajectories to acquiring expertise in clinical thinking. We have studied the cognitive components that differentiate learners along the learning trajectory and have studied experts in particular to see the types of reasoning paths that can be taken in these contexts. Bioworld is a highly interactive environment that is based on the assumption that expertise is acquired through the deliberate practice of the cognitive components that encompass proficiency in a particular domain (Ericsson, 2002). By identifying such components, medical student performance can be traced and appropriate feedback can be provided when and where they might need scaffolding. In this way, medical students can deliberately practice their diagnostic reasoning skills in a supported setting in a condensed time frame so that their hypotheses are linked to their actions and interpretations of patient data. Interaction and learner control are two variables that lead to more natural learning than found in traditional classrooms (Halverson & Collins, 2006). Halverson & Collins (2006) describe how dynamic interaction with a computer environment is more engaging since learners see the consequences of their actions. Learners need to comprehend what this feedback means and use this understanding to guide their future actions.

Building Expert Models

We have examined expert models of clinical reasoning in two ways. First, we observed medical instructors tutor students in the context of specific patient cases and found that they teach students by thinking out loud as they go through the steps of reasoning about specific patient cases. Given this natural tendency, we asked medical instructors to do think-alouds as they solved patient cases using

Bioworld (Gauthier, 2009; Gauthier & Lajoie, 2008). We tested multiple experts per case in order to establish a robust problem space that represents multiple plans and actions that are appropriate for each case. We collected multiple sources of evidence from participants. Computer trace data was collected with respect to every plan and action that participants took to solution including the diagnoses they made, the evidence they collected to solve the case, etc. This data was merged with the verbal protocols of how participants solved the cases. In addition, screen recordings of what participants did and what they said at particular points in time were used to contextualize the trace data. Multimodal representations were then created of the solution process to communicate with participants about their own thinking as well as provide opportunities for them to validate or change the way in which we represented their reasoning. Participants could inspect their decision tree and validate the researchers interpretation of the diagnostic reasoning space. This visual representation included a sequential summary of their transcript along with links to original data collected by Bioworld (see Figure 1).

We found that medical consensus was reached for final diagnoses, but the solution paths to reach diagnoses vary. The importance of representing the diver-

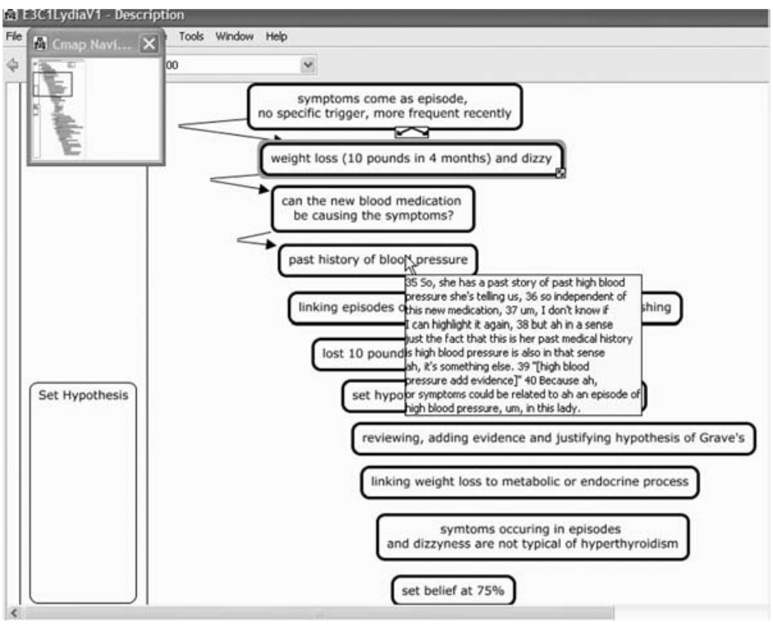

FIGURE 1
Extract of visual representation of the path with mouse-over.

sity in solution paths is that expert explanations at specific nodes in the problem space can help learners understand the significance of the underlying mental representations of experts as they solve such problems. These representations can help determine where and when tutoring feedback can be provided to students in the context of their clinical reasoning about a case. In the future we can use such maps as a placeholder to automate scaffolding.

We have started to test the assumption that interacting with one's own knowledge representations and those of others can enhance learning (White, Shimoda & Frederiksen, 2000; Schwartz, Blair, Biswas, Leelawong & Davis, 2008). Pilot data have shown that visualizations of expert trajectories provide alternative perspectives for thinking about the solution process (Gauthier, Naismith, Lajoie, & Wiseman, 2008). For example, one student stated he had a greater awareness of diagnosis as a process rather than just an outcome:

> I kept thinking that it was the drug itself causing all the vascular problems, and didn't recognize the problem of a 37 year old woman actually having high blood pressure that required treatment in the first place. So I arrived at a drug induced arrhythmia which could have explained her symptoms, but it would definitely be more likely in an older patient with more risk factors for essential hypertension. I have to pay more attention to the baseline evidence of the patient rather than just focusing on the most recent data.

Another student stated how and why his or her approach might be different than that of experts: "I went directly to the diseases that I was most familiar with, like hyperthyroidism and panic attacks. I think the expert had more familiarity with a condition like pheochromocytoma and so it occurred to him or her more immediately." We are planning a full scale study to see whether such visualizations give novices an advantage over simple recaps of expert evidence collection traces.

In the next section, a different use of computers as cognitive tools is supported for emergency medical situations where medical teams work together to manage patients.

MEDICAL TEAMS

Physicians in emergency medicine need to make rapid decisions that are based on appropriate forms of communication with both the patient, if possible, and the medical team handling the emergency. Decision making in the real world, where decisions are made under extreme time pressure have been conducted in several domains (see the literature on naturalistic decision making) (Klein, Calderwood, & Clinton-Cirocco, 1986; Cannon-Bowers & Salas, 1998; Cannon-Bowers, Salas & Converse, 1993; Lajoie, Azevedo, & Fleiszer, 1998; Leprohon & Patel, 1995) The deteriorating patient (DT) activity is designed to immerse students in such a context. A medical instructor designed the 'deteriorating patient' (DP) activity as an interactive role play that simulates actual medical emergencies that internal medicine students encounter in emergency rooms (Wiseman & Snell, 2008). The teacher draws on his clinical and pedagogical expertise and acts as a coach as he plays the roles of the deteriorating patient and the duty nurse while challenging and scaffolding his students as they struggle to save the life of the patient. In this simulation, the instructor acts as the patient and the nurse and the students take turns as the physician who manages the patient. If the students make incorrect decisions the patient's condition deteriorates. When the students need help they ask other students to step in to solve the problem. The instructor scaffolds the students in the context of their decision-making. Students learn to ask the right questions, order the correct tests, and manage the situation. Students also learn to manage stress and make decisions quickly based on the patient's rapidly deteriorating medical condition, which are key ingredients for success in managing emergency situations.

Though the DP was already a successful simulation, we wanted to increase the participation of those students who were observing. Consequently, we introduced collaboration as well as technological support to this simulation with the goal of supporting learning throughout the role-play activity (Lu & Lajoie, 2008). We designed computers as cognitive tools to facilitate group decision-making and communication in the context of managing a patient in the deteriorating patient simulation. We studied collaboration and decision making of a control group that did not have technological support tools compared to those with the technology.

The control group had a traditional whiteboard (TW) that they used to document their medical arguments whereas the experimental group used an interactive whiteboard (IW) that was supported by technology. More specifically, they had laptops that interfaced with the IW and each sub-group could add information to the medical argument by using a structured template for building, annotating and sharing arguments (see Figure 2). Both conditions were asked to solve the 'deteriorating patient' activity.

In the BioWorld work described earlier, we demonstrated the power of providing expert pedagogical models for student reflection and assessment. In the current study we demonstrate the advantage of peer reflection and shared knowledge that is constructed through consensus building. Peers reflect the problem list as it

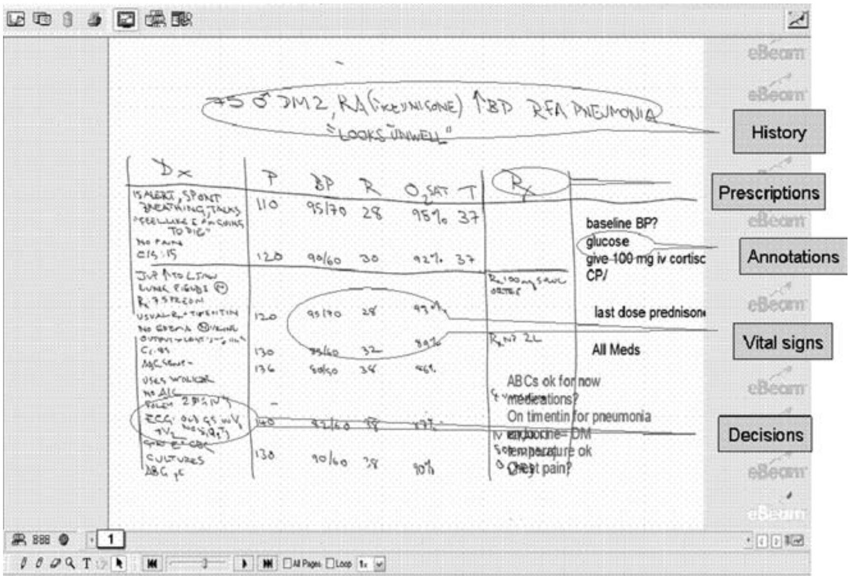

FIGURE 2
Screenshot of Interactive Whiteboard where students build, annotate and share medical arguments.

is documented and scaffolded by the instructor. The question posed was: do technology-supported teams make better decisions and communicate more than those without technology support?

The methodological challenges confronting this study involved describing and interpreting a complex clinical teaching activity that involved interactive role-playing in the context of solving a case. Teaching clinical reasoning is difficult at best but the deteriorating patient activity did provide a sense of realism that afforded the type of naturalistic decision-making required in ill-structured problems. Verbal discourse and computer annotations were analyzed with respect to how the introduction of technology mediated the students' communication and problem-solving activities. We found that students in the technology condition communicated more and established common ground earlier in the activity then the traditional whiteboard condition and that this communication led to more effective problem-solving (Lu & Lajoie, 2008).

Teacher scaffolding was investigated in both conditions. The teacher scaffolded less in the technology condition and his assistance faded over time whereas the opposite results occurred in the TW condition (Lu, Lajoie, & Wiseman, submitted). Our results support the conclusion that the technology helped establish common ground early on in the activity and reduced the need for human tutoring given the technology tools. The fact that technological tools helped establish shared common ground earlier in the DP activity led to a decreased need to communicate in the later stages of problem solving making patient management more efficient than in the control group.

COGNITION, EMOTION, TECHNOLOGY AND MEDICINE

Modelling the Medical Brain and Heart

As stated previously, researchers in the learning sciences and those in the area of artificial intelligence and education are interested in broadening our definition of what a model of the learner should include. We are broadening our medical research to refine learner models to consider unique intersections between cognition, emotion and culture. The role that affective states play in learning (Craig, Graesser, Sulliins, & Gholson, 2005) and how the use of technology for learning can be related to variation in culture (Ishida, Fussell, & Vossen, 2007) are quite recent extensions in the learning with technology literature. In the context of BioWorld we are planning studies to examine how emotional patient content affects physician decisions, reasoning and confidence levels (Blanchard, Volfson, Hong, Lajoie, 2009). For example, does stress inducing content change the accuracy or nature of reasoning, does it change the direction of confidence in the decisions one makes in the context of computer learning environment. We are also examining how the physicians' mood influences decision-making (Ranellucci & Lajoie, 2009). For instance, we hypothesize that physicians who are in a negative mood may become more analytical or detail-focused in their decision making whereas positive mood induction may result in creative problem solving in complex cases. In the context of our work with the deteriorating patient activity we are considering ways of looking at the role of stress in team management of a patient as well as the role of competition and collaboration as a way of increasing the level of interest and challenge in the simulation activity.

Along with new medical models we have been considering new forms of assessment. Throughout the paper we have described the importance of converging different data sources to provide a more robust profile of evidence of the learner as they problem solve. One could call this process data. In the BioWorld context we are looking at the process of diagnostic reasoning, how hypotheses of diagnoses are linked to patient symptoms and sources of patient evidence that is then linked to diagnostic test taking. We also looked at the role of self assessment as it occurs after completing the case where learners can inspect their solutions and compare them with expert solutions (Gauthier, Naismith, Lajoie, & Wiseman, 2008). In terms of the DP problem we are interested in how communication patterns in groups (on line and face to face) influence decision-making.

We are also interested in developing tools to assess where the learners begin, prior to using BioWorld, where they end, and what they are able to transfer after practicing in BioWorld. For this reason, we find the preparedness for learning (Bransford & Schwartz) literature informative as a methodology for examining differences along a learning trajectory. For instance, prior to interacting with BioWorld patient cases, are there differences between medical student cohorts and physicians, in their preparedness to learn as indicated by the quality of the questions they would ask prior to problem solving. A sample test question might be: A 22-year-old university student, comes to a walk-in clinic on a Monday complaining that he feels lousy, and has been up all night vomiting. What questions would you ask the patient in order to diagnose and manage the problem? What questions would you ask in order to research how to diagnose the patient problems? This task would provide evidence of whether the participants know how to conduct a patient history as well as what physical exam questions they would entertain, what hypotheses they might have, how they would link hypotheses to patient directed questions, and how they would follow up with appropriate tests to confirm or disconfirm their hypotheses. Administering this type of test before and after BioWorld would be a good measure of understanding prior to BioWorld and transfer of knowledge post-BioWorld.

In the context of the Deteriorating Patient activity we are building a video based critiquing tool that is designed for the purpose of making assessment criteria transparent. The importance of using multiple means of making assessment criteria visible to learners has been documented (Collins, Hawkins, & Frederiksen, 1994; Frederiksen & Collins,1989). Our assessment criteria will be embedded into a library of DP exemplars where students can examine video vignettes and critique the vignettes based on specific assessment criteria that pertain to the emergency medicine algorithm of patient management. Students could discuss and assess the videos together, entering their data into the computer and comparing their analysis of physician performance with an expert debrief of what should have been done. This activity parallels work done in the area of critiquing statistical investigations as a way of assessing what students understand about the appropriate assessment criteria (Lajoie & Lavigne, 2007) prior to producing their own investigations. In the medical example we can assess what students understand and how they work as teams using the exemplars prior to conducting their own activity. Participants would be instructed to critique the emergency medicine video on the following assessment criteria:

a. What did the physician do well? b. What can the physician improve? c. What aspects of the emergency medicine algorithm did the physician attend to in managing the patient? d. What did the physician miss? e. How did he manage airway, breathing, circulation, drugs, environment and fever in the patient? f. How confident are you in your assessment of the physicians' performance? g. What would you have done differently than the physician?

Medicine and Culture

As we consider the importance of how learning is situated in a context and socially constructed in the context of a group we must consider culture as part of the social context. For example, there is a medical culture of how physicians work together which is often portrayed in terms of a hierarchy of what type of medicine is seen as more prestigious or difficult as well as how physicians work with other medical professionals (i.e., nurses, technicians, etc.). We also need to consider how physicians from different cultural backgrounds (international origins, ethnicities as well as intergenerational) communicate with each other and perhaps, more importantly, how physicians communicate with patients from different cultural backgrounds (Blanchard, Mizoguchi, & Lajoie, 2009). These are complex questions that need to be asked and explored in terms of building more appropriate medical models that will inform teaching and learning.

DISCUSSION AND CONCLUSION

This paper has provided an overview of some of the guiding questions, answers and new questions that have driven the field of research about computers as cognitive tools. The core of this field has centered on issues involving models of human performance, whether or not computers can model human performance, whether they should model, who else can model expertise using technology as a tool, the role of groups, peers and significant others in supporting learning with technology etc. Most recently we have moved beyond modeling and supporting an individual through cognitive tools, to modeling groups, teams, emotions, and cultural differences. I have contextualized the discussion of such complex issues in the context of research that I have been conducting in the field of medicine. Examples of the types of data that can be used to develop models of both individual and distributed problem solving in medicine were provided with respect to expert models, the role of the group, affect and culture. Complex forms of data convergence were described, using such sources as verbal protocols, discourse, computer annotations, computer log files and screen captures have been analysed and integrated in innovative ways to provide a more complete understanding of learning and pedagogy in medical situations. We have begun to explore how technology can provide a common space for problem solving involving complex interactions between collaborative and tutored groups and how such activity can be analyzed to uncover the underlying processes of grounding, co-construction, scaffolding, and fading. We provided evidence of how one might develop the type of domain based models of learning and performance suggested by the National Research Council (2001) as a precursor and guide to better forms of assessment. Furthermore, we have described additional forms of assessment that we plan to use to measure the impact of modeling emotion and culture. We have started to demonstrate how learning trajectories can be identified as a first step in developing a model of proficiency in these situations. We have also tried to delineate different techniques that can be used to understand both the individual learner's understanding as well as the group when social mediation and consensus building are key requirements in a dynamically changing setting. We looked at the role of technology in both settings from the perspective of instruction, assessment and research. Our goal has been to convey the importance of the interdependence of these tools when establishing more informed interpretations of the phenomenon in question.

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