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Case-based reasoning-inspired approaches to education

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Abstract

This commentary briefly reviews work on the application of case-based reasoning (CBR) to the design and construction of educational approaches and computer-based teaching systems. The CBR cognitive model is at the core of constructivist learning approaches such as Goal-Based Scenarios and Learning by Design. Case libraries can play roles as intelligent resources while learning and frameworks for articulating one's understanding. More recently, CBR techniques have been applied to design and construction of simulation-based learning systems and serious games. The main ideas of CBR are explained and pointers to relevant references are provided, both for finished work and on-going research..

1 Introduction

Over the years the large amount of research on reasoning processes involved in case-based reasoning (CBR) has resulted in substantial insights into the application of the theory toward real world problems in several areas, including education. Examining CBR as a plausible cognitive model, case-based reasoning research makes several claims with respect to the cognition of learning and suggestions about promoting learning effectively. First, CBR claims that concrete authentic experiences provide a richer and therefore more memorable and accessible representation than do abstract principles, suggesting an approach to education in which learning is embedded in problem solving experiences and ways of interpreting those experiences to be able to remember them at appropriate times in the future. Second, CBR shows how episodes of failed reasoning can provide a focus for new learning, pointing out what needs to be learned and providing links for integrating new knowledge with existing knowledge structures, suggesting the need for learners to have opportunities to fail, explain, and test newly formed knowledge as part of their educational activities. Third, CBR points out how learning based on failures and surprises can enable the anticipation of problems by reasoners so they can avoid those same failures in the future, suggesting kinds of reflection on experiences that will promote productive learning from experience. Fourth, CBR shows the kinds of content of cases that allow them to be used for productive inference in the future, suggesting kinds of interpretations of experience that are likely to lead to better use of newly-learned knowledge and capabilities.

Kolodner (1997) explains how these principles emerge from CBR's cognitive model and provides examples of CBR-inspired educational approaches and software tools. According to CBR, the iterative cycle of applying knowledge, interpreting feedback, explaining results, and revising memory provides a model for promoting learning (Kolodner, 1993; 1997; Schank, 1982; 1999). From this insight, two kinds of suggestions can be distilled with respect to education. First, CBR suggests ways of orchestrating and sequencing learning-by-doing classroom activities, including the roles teachers and peers can play in that orchestration and ways of integrating hands-on activities. Second, this insight suggests several kinds of software tools for enhancing reasoning and for promoting productive kinds of reflection.

2 Goal-Based Scenarios and Learning by Design

Two styles of education that emerge from this insight are discussed in depth in Kolodner (1997) and include Goal-Based Scenarios (Ferguson *et al*., 1992; Schank *et al*., 1994; Schank & Cleary, 1994) and Learning By Design (LBD) (Hmelo *et al*., 2000; Kolodner *et al*., 2003a; 2003b; 2004). In both, learning is in the context of attempting to achieve some mission or design challenge. Learners become curious about learning because they want to achieve the challenge, and they generate questions about things they have a need to know.. After carrying out investigations and/or getting answers to questions by querying resources, they apply what they've learned to achieving the mission or challenge. Important in both approaches is that learners have a way to test their solutions and experience the outcomes. If outcomes are different than expected, they have reason to want to explain why, leading to new questions, the need for additional investigations or querying of resources, and refinement of their understanding or reasoning.

Goal-Based Scenarios have learners achieve missions in simulated worlds. For example, in the Sickle Cell Counselor (Bell *et al*., 1994), learners are asked to give genetic advice to a simulated husband and wife – what is the chance that a baby they will have will have Sickle Cell Anemia? They carry out simulated blood tests on the computer, they use the computer to create a punnet square that they can use to calculate probabilities of the baby inheriting sickle cell, and they make a recommendation to the simulated couple. They then fast forward to a year later and talk to the simulated couple again. If the couple's experience was different than what the learner suggested, the learner finds out quickly that his/her reasoning was faulty and gets help, within the system, at debugging his/her reasoning.

In Learning by Design, on the other hand, learners design and build working devices and get their feedback from the real world. For example, in LBD's *Vehicles in Motion* challenge, learners are asked to design and build a small vehicle and its propulsion system. It has to go over several hills and then travel in a straight line a certain distance. Each time it fails to go straight enough or far enough provides another opportunity to reflect on the science of forces being used to inform the vehicle's design. The vehicle's behavior gets better and the learners' understanding of forces get more refined with each iteration of the design.

2.1 Case libraries and case-authoring tools for education

Kolodner *et al*. (2004) provide a variety of examples of software tools suggested by CBR and provides citations to them. Goal-Based Scenarios and Learning by Design, for example, use case libraries as a resource. In the course of solving a problem or understanding a situation or trying to achieve a challenge, learners can access case libraries to find annotated examples that can help them move forward with their reasoning. Archie-2 (Domeshek & Kolodner, 1993; Zimring *et al*., 1995) is an example of one such resource; it holds cases representing architects' experiences in designing public libraries. Used while designing a new public library or another type of public building, its cases provide suggestions about layout, way-finding, and other issues facing designers.

Research shows that case libraries are useful as more than resources. For example, research on use of the Archie-2 system showed that students who authored cases in the case library learned more than those students who just used the cases for advice. The implication for education is that recording and organizing experiences for other learners can act as an effective tool for educating those who are authoring cases. The activity of authoring cases can serve as a vehicle for promoting the kinds of reflection on experience that case-based reasoning's cognitive model tells us is important for learning from experience.

Case authoring, on the other hand, may become a bottleneck when building case-based educational systems if the cases must be authored from scratch by tutors. Possible solutions to alleviate the engineering problem of authoring cases are to use the output of a problem solving system as the input to the authoring system (Bichindaritz & Sullivan, 2002) or to extract the cases from the corporate memory of an existing knowledge management system, when available (Minor, 2002).

2.2 Evaluating CBR's contributions to education

There has not been a great deal of evaluation and assessment of case-based tools and pedagogical approaches, but what does exist (e.g., Kolodner *et al*., 2003a; 2003b; 2004) shows positive indicators. Students learn content at least as well and usually better than peers learning in classrooms that use more traditional pedagogies. Teachers and trainers who use CBR-informed materials come back energized. Moreover, teachers feel that they are able to reach more of their students with this methodology. Most exciting in these assessments, perhaps, is the evidence that learners in CBR-inspired classrooms are learning to reason expertly. Studies reported in (Kolodner *et al*., 2003a; 2003b) show that learners in Learning by Design classrooms collaborate better with peers, participate better in scientific reasoning, and specifically make reference to what they experienced and learned from previous classroom experiences than do their peers learning through other approaches. Most importantly across the levels (K through college through training) and ages of learners is that, when CBR's suggestions are carried out well, students learn targeted skills and content, collaborative behavior, and meta-cognitive practices in ways that are applicable to a variety of situations.

3 Looking towards the future

What does the future bring? We believe that CBR-inspired educational approaches will be making their way more into the e-learning mainstream. For example, a curriculum for computer science education has been designed based on CBR principles at Carnegie Mellon University West in California. All learning is through challenges, and learners have the opportunity to test what they are doing in simulations of the real world. A review by Chapman (2003) describes more than 50 simulation-based e-learning vendors, reflecting a growing interest in constructivist learning environments, perhaps due to what Aldrich (2004) reports: The first generation of content-based e-learning systems were not as successful as predicted.

While this state of the world has opened the future to simulation-based e-learning, we feel it important to caution that not all simulation-based learning is equal. CBR warns us that unless learners can interpret outcomes well, they will not be able to learn well from their experiences. This suggests that the feedback given by simulations needs to be specific enough about outcomes for learners to be able to clearly identify their misconceptions and reasoning errors. It suggests, too, that simulations need to be embedded into learning environments that provide access to help with identifying those misconceptions. CBR suggests, too, that learning from simulation will happen best when the simulation is used as a tool to help the learner achieve an appealing challenge or mission. Related efforts focus on game-based learning systems (Prensky, 2001; Gómez-Martín *et al*., 2004) that embed simulations into serious games to promote motivation in the learner. Also related to motivation and amenable for the application of CBR ideas is the use of animated pedagogical agents (Lester *et al*., 2001) – lifelike computer characters inhabiting a virtual world for pedagogical purposes who can tell the learner the story she needs to hear for solving the problem at hand. CBR ideas, and in particular, goal-based and design-based approaches, are especially relevant to simulation-based learning, and synergies should be explored in the coming years (Gómez-Martín *et al*., 2005).

Kolodner (1997) predicted "The use of such a software environment (simulations) across many different problem-solving and design experiences will promote learning of a full range of cognitive, social, and self-directed learning skills..." In many ways, this prediction has become reality. The huge evolution of graphics technology, both in software and graphics cards, mainly driven by the game industry, has led to a situation where simulations are relatively cheap to build and use within e-learning systems (Jiménez-Díaz *et al*., 2005). We encourage those who are designing simulation-based learning technologies to take CBR's recommendations about promoting learning into account in their designs.

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