

Interactive Conceptual Tutoring in Atlas-Andes

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Motivation

Atlas-Andes is a dialogue enhanced model tracing tutor (MTT) integrating the Andes Physics tutoring system (Gertner & VanLehn 2000) with the Atlas tutorial dialogue system (Freedman *et al.* 2000). Andes is a MTT that presents quantitative physics problems to students. Each problem solving action entered by students is highlighted either red or green to indicate whether it was correct or not. This basic feedback is termed *red-green feedback*. Furthermore, when students get stuck in the midst of problem solving and request help, Andes provides hint sequences designed to help them achieve the goal of solving the problem as quickly as possible. Atlas provides Andes with the capability of leading students through directed lines of reasoning that teach basic physics conceptual knowledge, such as Newton's Laws. The purpose of these directed lines of reasoning is to provide a solid foundation in conceptual physics to promote deep learning and to enable students to develop meaningful problem solving strategies.

While students in elementary mechanics courses have demonstrated an ability to master the skills required to solve quantitative physics problems, a number of studies have revealed that the same students perform very poorly when faced with qualitative physics problems (Halloun & Hestenes 1985b; 1985a; Hake 1998). Furthermore, the naive conceptions of physics that they bring with them when they begin a formal study of physics do not change significantly by the time they finish their classes (Halloun & Hestenes 1985b). Similarly, MTTs in a wide range of domains have commonly been criticized for failing to encourage deep learning (VanLehn *et al.* 2000). If students do not reflect upon the hints they are given, but instead simply continue guessing until they perform an action that receives positive feedback, they tend to learn the right actions for the wrong reasons (Aleven, Koedinger, & Cross 1999;

Aleven *et al.* 1998).

This shallow learning problem was first addressed in the Andes tutoring system with the development of the Conceptual Helper (Albacete 1999). In contrast to the basic Andes hint sequences that are available upon request, the Conceptual Helper offered students unsolicited help as soon as the student showed evidence of needing that help. Help was provided in the form of mini-lessons involving text and graphics that provided students with detailed lines of reasoning promoting a conceptual understanding of physics. A significant difference was found between an Experimental group using Andes with the added Conceptual Helper in comparison with a Control group using only the standard Andes hint sequences and red-green feedback. The text and graphics provided by the Conceptual Helper allowed students to learn by means of receptive learning, which has been demonstrated to be successful when students have both the necessary prior knowledge to integrate the desired new knowledge in a meaningful way and sufficient motivation to learn meaningfully rather than in a shallow or rote manner (Ausubel 1978).

The difference between the type of help offered via the Conceptual Helper and the type of help offered by Atlas is that Atlas provides interactive directed lines of reasoning, such as that displayed in Figure 1. In the Atlas directed lines of reasoning, students are lead step by step by a sequence of questions designed to guide them into discovering conceptual knowledge as independently as possible. Interactive directed lines of reasoning provide advantages over the receptive learning approach. Firstly, because students are required to answer questions at every step in the directed line of reasoning, when their answer reveals a lack in required prior knowledge, it can be addressed in order to allow the directed line of reasoning to proceed meaningfully. Thus, learning is tailored to the individual differences in prior knowledge among students. Secondly, requiring students to answer questions requires students to participate in an active way. Passive learning is not an option as it is in receptive learning.

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Tutor1: Let's think about the difference between speed and velocity. A closely related distinction is that of the difference between distance traveled and displacement from the origin. Take as an example a bumblebee flying from point A to point B by means of a curvy path. If you draw a vector from point A to point B, you will have drawn the bee's displacement vector. What does the displacement vector represent?

Student1: The bee's distance.

Tutor2: The displacement vector only represents the net change in position accomplished by the bee's motion. So the displacement vector does not tell you how far the bee traveled. It only tells you the net change in the bee's position. If you want to know the actual distance traveled by the bee, what entity do you have to measure the length of?

Student2: The path of the bee.

Tutor3: The bee's displacement vector is obviously a vector. Is the actual distance traveled by the bee a vector or a scalar?

Student3: Scalar.

Tutor4: So distance traveled is the scalar counterpart to displacement, which is a vector quantity. Now, can you tell me what is the difference between speed and velocity?

Student4: Speed is a scalar and velocity is its vector quantity.

Tutor5: So when you measure the bee's speed, do you want to use the distance traveled, which is a scalar, or the displacement, which is a vector?

Student5: The distance traveled.

Tutor6: So the equation for speed is the length of the path traveled by the body divided by duration of the motion, regardless of how curvy the path is, even if the path leads back to where the body started from.

Figure 1: Example interaction between student and Atlas

Overview

In a prototype version of Atlas-Andes (Freedman *et al.* 2000), interactive directed lines of reasoning were linked into Andes at the end of the standard Andes hint sequences. In order to increase exposure to conceptual tutoring, however, in the current fully integrated version of Atlas-Andes interactive directed lines of reasoning are linked into Andes via the Conceptual Helper, replacing the original non-interactive mini-lessons. Thus, directed lines of reasoning are provided in an unsolicited fashion when the students first show evidence of needing such tutoring by performing buggy problem-solving actions.

Fifty separate directed lines of reasoning are currently provided that teach the basic conceptual rules targeting all aspects of Newtonian Mechanics. The knowledge sources required by the general Atlas tutorial dialogue system (Freedman *et al.* 2000) were developed using the KCD Authoring Tool Suite described earlier in this volume (Rosé 2000). Each of the fifty directed lines of reasoning consists of a sequence of tutorial goals, each realized as a question possibly accompanied by a short explanation. A set of remediation goals is associated with each of a number of expected wrong or partial student answers. Directed lines of reasoning corresponding to each associated remediation goal are also included. Thus, the directed lines of reasoning provided by Atlas-Andes take on a hierarchical structure, allowing a great deal of flexibility in adapting to specific

student needs.

Remediation directed lines of reasoning take on a number of different forms. In simple cases, the student is simply presented with a short explanation to clear up a detected misconception or missing piece of information. In other cases, a more specific or simpler version of the previous question is given in an attempt to draw the correct answer out of the student. In cases where the missing or faulty knowledge can be decomposed into a sequence of more basic pieces of knowledge, a multi-step directed line of reasoning is used. Since it is impossible to fully anticipate the complete range of possible answers students may give, an anything else case is included for every question appearing in any directed line of reasoning. This enables the system to be able to respond no matter what the student types as input. The remediations for the anything else cases are designed with the intent of sounding natural almost no matter what the student types.

Example Interaction

Figure 1 contains a typical example dialogue between Atlas-Andes and a student. This directed line of reasoning was designed to lead the student into an understanding of the differences between speed and velocity, first in terms of what they are, and then in terms of how they should be computed. As is typical in the Atlas-Andes directed lines of reasoning, an every day scenario is used to illustrate the concept. Familiar scenarios are

used in order to make the directed lines of reasoning accessible to the broadest possible audience.

In the first tutor turn, the student is presented with an *advance organizer* (Ausubel 1978), in order to set up the student's expectation for what the tutor's argument will be and to bridge the gap between what the student may already know and what the student should learn. In the same turn, the tutor introduces the scenario that will be used to point the student towards the desired conclusions. The turn ends with a question about what is represented by a displacement vector.

The student responds in the first student turn by giving a common wrong answer, namely that displacement is the distance traveled by the bee. The distinction between distance and displacement was introduced in the advance organizer as a relevant piece of possible prior knowledge. This example dialogue illustrates how Atlas-Andes handles the case where the relevant prior knowledge is missing. The tutor begins to address the missing knowledge in the second tutor turn by briefly explaining the distinction between distance and displacement. A check question is then given to the student to ensure that the student has properly assimilated the explanation. The student responds with a correct answer, indicating that the tutor explanation was successfully integrated into the student's understanding.

Thus, the advance organizer is used to draw the student's attention to possible prior knowledge that is relevant to the current directed line of reasoning. But if that knowledge turns out to be missing, the tutor can address the student's deficit before proceeding. In this case, the advance organizer still serves the purpose of allowing the student to understand the relevance of the inserted remediation directed line of reasoning.

When the remediation subdialogue is complete, the tutor continues presenting the student with questions, which the student is able to answer correctly. The student arrives at the desired conclusion in the final student turn. The tutor then responds with a brief summary of the argument.

Current Directions

The Atlas-Andes directed lines of reasoning are currently being pilot tested. The fully integrated Atlas-Andes system will be evaluated in the context of a Freshman Physics course at the University of Pittsburgh in late September.

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