Intelligent Tutors: Past, Present and Future

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National Science Foundation
Outside of the School House

Soldiers learn with:
- Twitch speed vs. conventional speed
- Parallel vs. linear processing
- Graphics-based vs. text-based
- Connected vs. stand-alone
- Active vs. passive
- Fantasy vs. reality

No wonder school houses are boring!

(Catherine Beavis, Digitel Conference, 2010)
Training in the School House is Expensive and Boring

Information is instantly available.

Change is constant and rapid.

Distance and time do not matter.

Powerful tools are taken for granted.

Multimedia entertainment is omnipresent

Multi-tasking is how people work

(not not effectively).

**No wonder soldiers are bored in school houses!**

Chris Dede, Keynote Speech
The U.S. has slipped behind in the K-12 classroom.

• Only 30% of 8th graders and 21% of 12th graders scored proficient or higher in science (National Assessment of Educational Progress exams).

• The U.S. ranked 14th in reading, 17th in science and 25th in math (Program for International Student Assessment).

• Only 75% of high school students graduate, below the average (organization for Economic Co-operation and Development).

• U.S. has relinquished its lead and fallen to 9th in the production of young people with a college degree.
Past, Present and Future

Future, Past, and Present
Asynchronous, continuous learning, provided anytime, anywhere through a learning repository that provides real-time, seamless, ubiquitous training and assessment. The big need is for intelligent, instructional content.
The Motivation

Improved teaching:

- **2 Sigma** for human one-on-one tutoring
- **.50 Sigma** for interactive multimedia, (raises the median score from 50% to 69%)
- **1.05 Sigma** for intelligent tutors (raises the median score from 50% to 85%).

Reduced Cost:

~63% less less expense to provide instruction with technology.

Improved cost-efficiency:

Bring instruction to learners rather than bringing learners to the schoolhouse.
Some effect sizes for studies comparing Intelligent Tutors—
with more conventional technology-based instruction

Dexter Fletcher, *Effectiveness and Cost*
Active and Interactive

Active students using interactive learning objects on personal learning devices.

Objects will be intelligent, tailored to the needs, states and traits of individuals or group (battalion, crew) and based on natural language dialogue.

Personal devices, will be portable, be easy to use, have with high bandwidth.
Agenda

Past: Student, domain and tutoring knowledge

Current Intelligent Tutoring Systems

Future Intelligent Tutoring Systems

Discussion and Further Work
Past Intelligent Tutors

Definition of Intelligent Tutors

• Generative – generate appropriate problems, hints and help.

• Student modeling – assess the current state of the student’s knowledge

• Expert modeling – assess and model expert performance

• Teaching modeling — manage the teaching.

• Self-Improving – monitor, evaluate and improve its own teaching as a result of experience.
Main Drivers for this Change in Education

- **Artificial intelligence (AI)** leads to personalized training by modeling domain, student, tutoring and communication knowledge.

- **Cognitive science** leads to a deeper understanding of how people think, solve problems and learn; and

- **The Web** provides an unlimited source of information, available anytime and anyplace.
Intelligent Tutors Do Improve Learning

• Nearly the same improvement as one-on-one human tutoring.

• Effectively reduce by one-third to one-half the time required for learning.

• Networked versions reduce the need for training support personnel by about 70% and operating costs by about 92%.
Definition: Intelligent Tutoring Systems

- Student Knowledge
- Domain Knowledge
- Tutoring Knowledge
- Communication Knowledge
The Variety of Knowledge Represented in a Student Model

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>What is Represented?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topics</strong></td>
<td>Concepts, facts, procedures: Rules and steps explicitly identified. Skills: ability on skills, goal, plans and tasks. Declarative Knowledge expressed as facts about objects, events and their relations.</td>
</tr>
<tr>
<td><strong>Misconceptions</strong></td>
<td>Well-understood errors; <strong>Bug Library</strong>. The student model represents incorrect “buggy” knowledge in addition to missing knowledge.</td>
</tr>
<tr>
<td><strong>Learning Characteristics</strong></td>
<td>Learning rate, student preferences, habits and profile; type of thinking (Inductive, deductive). Degree of concentration (typing errors)</td>
</tr>
<tr>
<td><strong>Affective Characteristics</strong></td>
<td>Engagement, challenge, boredom, seriousness, level of concentration</td>
</tr>
<tr>
<td><strong>Student Experience</strong></td>
<td>User history, student attitude toward some statement; discourse, plans, goals, task experience, context of the user</td>
</tr>
<tr>
<td><strong>Stereotypes</strong></td>
<td>General knowledge of student’s ability and characteristics; Initial model of student.</td>
</tr>
</tbody>
</table>
The Simulated Patient

Cardiac Resuscitation

[Eliot, 1994]
Simulated ECG Traces

![ECG Trace](image1)

![ECG Trace](image2)
Definition: Intelligent Tutoring Systems

Student Knowledge

Domain Knowledge

Tutoring Knowledge

Communication Knowledge
Cardiac Resuscitation
[Elion, 1994]

Student Model

Domain Model

Biased to reach goal state

- vfib
- brady
- asys
- vtach
- sinus

Domain Model

- 60% in 10 sec
- 30%
- 10%
- 10% in 10 sec
- 25%
- 65%
- GOAL
- sinus
Protocol Recognition

Protocol Selection Based on Simulation State

Current Recommendation

Model-tracing Tutors

• Contain a cognitive model or simulation of an expert’s correct thinking in the domain.
  – The cognitive model is capable or correctly solving any problem assigned to the student.
  – The students’ actions are compared to those of the expert and if their actions diverge sufficiently, the tutor offers advice or feedback.
  – The tutor keeps track of trainee actions, such as making selections from a menu or drawing on graphical user interface.
  – Advantage is that when a trainee is lost the model tracing tutor offered advice within the context of the problem.
Definition: Intelligent Tutoring Systems

- Student Knowledge
- Domain Knowledge
- Tutoring Knowledge
- Communication Knowledge
What is tutoring knowledge?

An intelligent tutor uses a variety of objects (examples, explanations) to tutor the student.
# Tutoring Components

<table>
<thead>
<tr>
<th>Tutoring Components</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td><strong>Objects</strong></td>
<td>Explanation, example, hint, counter example, quiz, question, display, analog</td>
</tr>
<tr>
<td><strong>Actions</strong></td>
<td>Test, summarize, describe, define, interrupt, demonstrate, implication, application, teach procedure.</td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
<td>Teach step by step, ask student, move on, stay here, go back to topic.</td>
</tr>
</tbody>
</table>
# Representing Teaching Knowledge

<table>
<thead>
<tr>
<th>Classes of Tutoring Strategies</th>
<th>Automated System</th>
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<tbody>
<tr>
<td><strong>Human teaching</strong></td>
<td>Apprenticeship learning</td>
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<tr>
<td></td>
<td>Problem-solving/ handling errors</td>
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<td>Bug-based tutoring</td>
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<td>Tutorial dialogue</td>
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<td>Case-based reasoning</td>
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<td>Collaborative learning</td>
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<tr>
<td><strong>Learning theory</strong></td>
<td>Model-tracing/cognitive tutors</td>
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<td>Constructivist theory</td>
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<td>Situated Learning</td>
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<td></td>
<td>The Zone of Proximal Development</td>
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<td>Self-explanation</td>
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<td>Socratic Learning</td>
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<tr>
<td><strong>Facilitated by technology</strong></td>
<td>Animated Pedagogical Agents</td>
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<td>Virtual Reality</td>
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<td></td>
<td>Interactive Simulations and Illustrations</td>
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</table>
## Considerations Made by the Tutor

<table>
<thead>
<tr>
<th>About</th>
<th>Examples</th>
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<tbody>
<tr>
<td><strong>Student Personality</strong></td>
<td>Motivation: high to low Learning ability: independent to passive</td>
</tr>
<tr>
<td><strong>Knowledge Domain</strong></td>
<td>Knowledge-setting: contextualized to isolate; connected to disassociated. Knowledge type: Facts, ideas or theory</td>
</tr>
<tr>
<td><strong>Teaching Intervention</strong></td>
<td>A continuum from intrusive to non intrusive; active to passive</td>
</tr>
<tr>
<td><strong>Task Type</strong></td>
<td>Theory type: Case based (e.g., math); Understanding: (e.g., gravity) Problem Solving; cognitive skill consisting of units of goal- related knowledge.</td>
</tr>
</tbody>
</table>
Apprenticeship

Lajoie and Lesgold, 1992; Sherlock
SHERLOCK

• Computer-based coached practice environment driven by a dynamic trainee model.
  – Used by Air Force trainees (F-15 manual avionics technicians) to learn difficult skills of troubleshooting the electronic equipment they use to make diagnoses in faulty devices.
  – Test station
Cognitive Apprenticeship behind SHERLOCK

• Learning is situated in a social context similar to those in which the skills will be used
• Both novice and master are active participants in the learning environment
• Cognitive processes are externalized and displayed for inspection
Cognitive Apprenticeship behind Sherlock (2)

- Modeling, coaching and fading are essential.
- Learners perform with support (coaching) that is gradually withdrawn (fading).
  - Explicit models of student competence is used to drive coaching and fading.
  - Coaching is individualized by giving different levels of help according to the student’s current state of achievement.
The Virtual Sand Table: Intelligent Tutoring for Field Artillery

Wisher, Macpherson (ARI), L. Jared Abramson and David M. Thornton (GMU), and James J. Dees (U.S. Army Training and Doctrine Command).

Students deployed multiple launch rocket system assets during a reconnaissance and selection of position task. Two-dimensional view with one student’s solution to the problem of emplacing a Company in a 3 km area of the National Training Center.
RESULTS Sandbox Tutor.

The tutor replicated the training with the added advantage of informative feedback and computer-based coaching during the exercise. Results, as measured by a hands-on performance test, indicated superior performance by the Virtual Sand Table treatment group, with an effect size of just over one standard deviation.
The Zone of Proximal Development

• The distance between the development level and the potential development with adult or peer guidance.
  – a trainee can perform a task with guidance or with the help of a peer that could not be achieved by his/herself.

  – Vygotsky believed that what a person can perform today with assistance he will be able to perform tomorrow independently.

Cognitive Response to Affect. from Murray & Arroyo (2002)
Definition: Intelligent Tutoring Systems

Student Knowledge

Domain Knowledge

Tutoring Knowledge

Communication Knowledge
Communication Knowledge

Modes, methods and technology to support trainee interaction.

• React to the student’s work;
• Demonstrate that the student’s thinking can be followed;
• Reassure the trainee that he/she has reached the right conclusion for the right reason.
Virtual reality environments typically consist of head-mounted displays and data glove worn by the person on the right. (a) ISI, University of Southern California, Project VET; (b) Virtual Reality Exposure Therapy, Georgia Tech, USA.
Training for a gas turbine propulsion system (left) aboard US Navy surface ships

The tutor places trainees in the space and points to the high-pressure air compressor (HPAC), part of the propulsion system (left).

STEVE, Lewis Johnson, ISI, CARTE
Team training in virtual reality

STEVE was assigned a role within an overall task to monitor another agent.
Herman was a pedagogical agent in Design-A-Plant. Herman watched as students selected the appropriate roots for a plant in an Alpine meadow (left). Then Herman congratulated the student on a correct plant design (right).

James Lester, University of North Carolina
Design-A-Plant agent behavior
Information on How to Build Intelligent Tutors

Student Knowledge

Domain Knowledge

Tutoring Knowledge

Communication Knowledge

Shameless Plug
Agenda

Past: Student, domain and tutoring knowledge

Current Intelligent Tutoring Systems

Future Intelligent Tutoring Systems

Discussion and Further Work
Current Intelligent Tutors

Success stories

**Cognitive Tutors (algebra)**
Adaptive scaffolding on algebra problems
More than 500,000 students per year, middle and high schools. Effect sizes: 1.2 and 0.7 on experimenter-designed tests; 0.3 on standardized tests.
25% more students pass state standardized exams; 70% greater likelihood of completing subsequent mathematics courses;

**ANDES (physics)**
Personalized help on 500 online physics homework problems.
More than 700 students. Effect sizes: 0.52 (non-science students); 0.223 (engineers); 1.21 (using diagrams); 0.69 (using variables).
9.8 - 12.9% increase in grades on hour-long exams, $p = 0.0001-0.03$.
Replaces grading homework; Manipulated only the way students do their homework.
Success stories

**Wayang (mathematics)**

Adaptive help and multimedia for 300 math problems.

More than 3,000 middle and high school students. Evaluations measures impact of support, problem difficulty and digital character on student performance.

10-16% more students pass state exams. Increased confidence and reduced frustration. System infers student emotion with 86.36% agreement with what students report.

**Project Listen (reading)**

Student reads passages aloud; system identifies words in context.

More than 3,000 students. Effect sizes range up to 1.3; 0.63 for passage comprehension. Differences in oral reading fluency (words read correctly per minute).

Students outgained control group in word comprehension (e.g., effect sizes of 0.56), passage comprehension, phonemic awareness, word identification, passage comprehension, and spelling.
ASSISTments (mathematics)

61,233 homework questions plus feedback

Randomized controlled tests; log data.

1500 users every day. In sum, 7500 students and 100 teachers, spanning 25 districts in Massachusetts and 12 districts in Maine. Effect size of 0.6.

Students improve half a standard deviation.

Crystal Island (microbiology)

Intelligent 3D game-based environments.

1450 students in grades 5 and 8.

Significant learning gains (about 2-2.5 question increase). Student learning and problem solving performance predicted by presence questionnaire.

Games motivate inquiry-based science learning with pedagogical agents; students use systems for a single, one-hour session; not yet part of everyday classrooms.
BILAT, Interview, A Military Simulation
Institute of Creative Technology,
University of Southern California

Contains:
**Domain Knowledge**;
how to improve market,
local law enforcement,
maintain power grid, etc.

**Student Model**
Performance, skills,

**Communication Knowledge**
Computer graphics,
gaming technology,
40,000 lines of dialogue
for virtual characters
BILAT, Interview, A Military Simulation
Institute of Creative Technology,
University of Southern California

<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>PREPARATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learn why market is not being used</td>
<td>OBJECTIVE REVIEW</td>
</tr>
<tr>
<td>Get Peace Cooperation</td>
<td>MEETING PARTNER</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>INTENDED OUTCOME</td>
</tr>
<tr>
<td>Research</td>
<td>PREP SHEET</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>REQUISITIONS</td>
</tr>
</tbody>
</table>

**Contact:**
- DTG:
- Copy 1 of 1

**Desired End State:**
- OPENING COMMENTS:
  - Taking Points
  - The market was part of a U.S...
  - The U.S suspects insurgents are...
  - The U.S believes that the...

**Intended Outcomes:**
- My Bottom Line

**Partner's Intended Outcome:**
- Partner's Bottom Line

**Possible Impasses:**
- Farid feels that the U.S. does not...
- Farid believes the U.S. to be...
- Farid is upset because Ali's...

**Possible Other Partner Issues:**
- Partner Issue Strategy

**Order Of Events**

**Relationship Building Topics**

**Exit Strategy**
BILAT, Interview, A Military Simulation
Institute of Creative Technology,
University of Southern California

You did a good job on relationship building and sending the right messages. However, threats and intimidation only hurt your position.

**Summary**
- Small Talk: 89%
- Negotiate: 33%
- End Meeting: 60%
- Use Interpersonal Skills: 0%

**Actions**
- Remove Kevlar: 0.00 seconds, correct
- Remove helmet and sunglasses: 0.02 seconds, correct
- Greet in Arabic: 0.04 seconds, correct
- Show photograph of wife: 0.06 seconds, incorrect
- Show photograph of husband: 0.09 seconds, correct
- Talk to Farid about the community's problems: 0.11 seconds, correct
- Compliment Farid on his leadership qualities: 0.13 seconds, correct
- Talk about your family: 0.15 seconds, correct
- Demand compliance in finding insurgents: 0.18 seconds, incorrect
- Compliment locality: 0.20 seconds, correct
- Ask Farid why the people are upset about the market: 0.22 seconds, mixed
- Negotiation: 0.24 seconds, incorrect

**Score Range**
- 0% - 40%: RED
- 41% - 80%: AMBER
- 81% - 100%: GREEN
Training Knowledge

GAME ACTIONS
- GIVE Candy
- GIVE Decorative sword
- ASK About family
- DO Menace

CHALLENGES
- IF (x > 3)
  - Challenge a
  - b
  - c

TRAINING OBJECTIVES
- LO#1
- LO#2
- LO#N
Motivation:
Most flight simulations require the presence of a human trainer; An adaptive tutor is needed to reason about the pilot and solution.

Solution:
The student model considers the pilot’s performance history, past training, patterns of performance, personality traits and learning style
The system diagnoses student errors and provides appropriate feedback
It encodes instructional goals, instructional planning and agents.
Helicopter Pilot Training
Stottler- Hinkley
Motivation:
Tactical skills can not be taught as methods or procedures
Trainees need extensive practice and to prioritize goals

Solution:
System provides a variety of tactical situations (ARI vignettes) along with Socratic questioning, hints and feedback
System evaluates each student’s reasoning by comparing solutions and rationale with that of expert response.
Motivation:
Tactical training typically requires 1 instructor per 2 trainees. Team members evaluate, coach and debrief other trainees. The goal is to reduce the number of instructors needed.

Solution:
Computer agent plays team member allowing students to practice concepts and principles. Speech-enabled graphic user interface supports dialogue; Soldiers converse with simulated team member to issue commands. Automatic evaluation of trainee; System infers tactical principles used by students.
Serious games

Mental contests, played with a computer in accordance with specific rules, that uses entertainment to further training and education.

Mike Zyda, IEEE Computer 38 (9), 2005
“From Visual Simulation to Virtual Reality to Games”
Crystal Island

• Teaches 8th grade microbiology

• Discover the source of an infectious disease plaguing island

• Narrative Learning Environment - facilitate students’ semantic encoding of new information and making commitments to long-term memory in the form of episodic memories

• Dynamic decision network (DDN) guides narrative

• Inquiry-based learning
Narrative planning

• Agent builds narrative elements based upon *narrative objectives*, *storyworld state*, and *student state*.

• Look at Bayesian network and n-gram models for learning students’ goals based upon their actions, to determine if sufficient “plot progress” has been made.

• Tutorial planner used to encourage *question formation, hypothesis generation, data collection, and hypothesis testing*. 
Blitz Game Studio’s *Triage Trainer*

Controlled trials in UK found Triage Trainer “to be statistically significantly better at developing accuracy in prioritising casualties and in supporting students to follow the correct protocol to make their decision” -- TruSim website
Agenda

Past: Student, domain and tutoring knowledge

Current Intelligent Tutoring Systems

Future Intelligent Tutoring Systems

Discussion and Further Work
VISION (once again)

Global learning repository.
The big need is for intelligent, instructional content.