

The Educational Software Gold Rush:
How the Learning Sciences and Advanced
Technology can Lead the Way

CSEDU-2013 Keynote

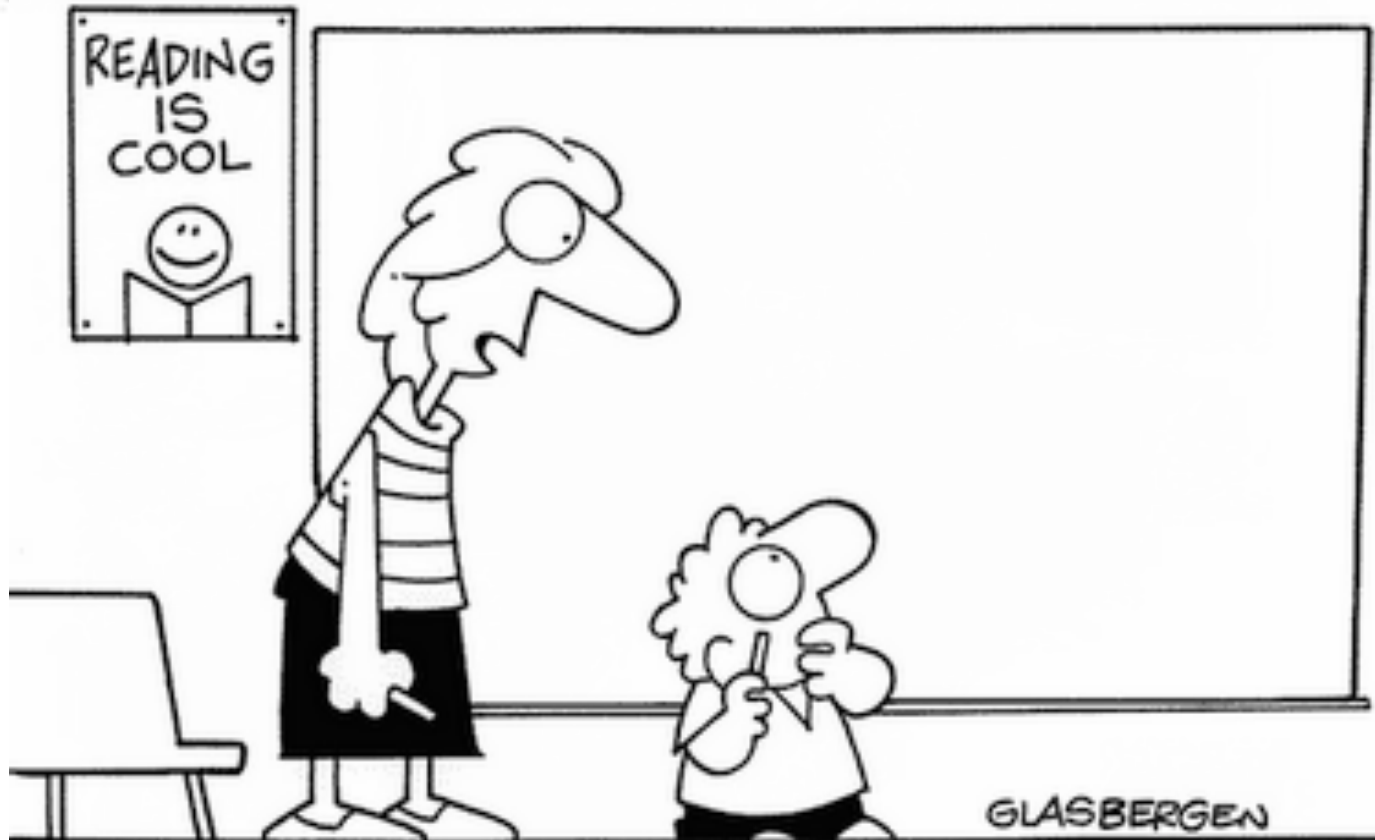
Dr. Bruce M. McLaren
Carnegie Mellon University

Carnegie Mellon

May, 2013

How do kids think and operate in today's world?

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**“There aren’t any icons to click. It’s a chalk board.”
use MapQuest?”**

The kids are practically begging us
to build technology for learning!

The Educational Software Gold Rush: How the Learning Sciences and Advanced Technology are Helping

Two “take home” messages of this talk:

1. There is currently a very strong, general belief – a “gold rush”, if you will – that computers and educational software can impact learning on a large scale
2. The Learning Sciences, as well as researchers and developers of advanced technology, have the scientific principles and approach to verify the gold rush *and* to help educational software succeed

Educational Technology

- Also “Instructional Technology” or “Instructional Media” – brief history:
 - 1900-1920: Silent Film (Edison, 1913: “Books will soon be obsolete in schools... Our school system will be completely changed in the next 10 years” Saettler 1968, pg. 98)
 - 1920-1940: Radio (Radio will provide “schools of the air” Saettler 1990, p. 199)
 - 1940-1980: Television (Government and Ford Foundation funding for public television stations)
- Yet, *none* of these technologies has revolutionized education... What about educational software? (1980-?? success ??)

Is Educational Software Making a Difference?

- Far from certain!
- On the Research side: Richard Clark, after reviewing hundreds of studies ...
 - “there are no learning benefits to be gained from employing any specific medium to deliver instruction”
 - “media ... are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes change in our nutrition”

Is Educational Software Making a Difference?

- On the Practical side: “Classroom Technology Faces Skeptics At Research Universities” by David F. Carr, Info. Week, Jan 2013
 - “What are the gains for students by bringing IT into the class? There aren't any. You could teach all of chemistry with a whiteboard. I really don't think you need IT or anything beyond a pencil and a paper”
 - “I've been very disturbed at the way this university has tried to ram these technologies down our throats,” grumbled one anthropologist

Is Educational Software Making a Difference?

The life's work of many prominent learning science and ed tech researchers counters this claim ...

Richard
Mayer



Paul
Kirschner



Edith
Ackermann



Diane
Laurillard



Pierre
Dillenbourg



Ulrich
Hoppe



Richard
Noss



Kurt
VanLehn



Ken
Koedinger



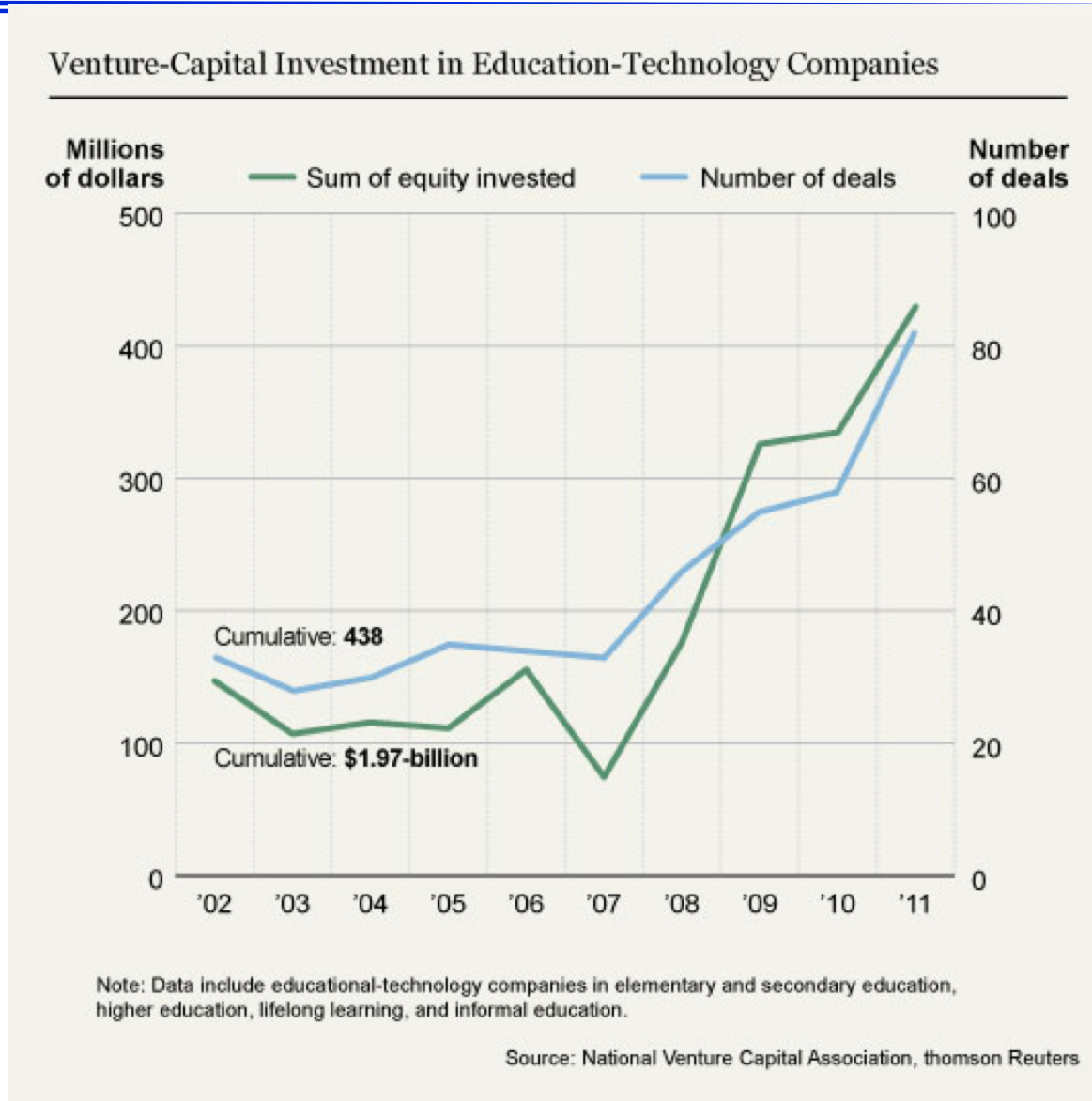
Nicolas
Balachef



Art
Graesser



And certainly money is being poured into educational technology...



From "A Boom Time for Education Start-Ups Despite recession investors see technology companies' 'Internet moment'" by Nick DeSantis, *The Chronicle of Higher Education, Technology*, March 2012

U.S. President Barack Obama on Educational Technology

“We will devote more than three percent of our GDP to research and development ... Just think what this will allow us to accomplish: solar cells as cheap as paint, and green buildings that produce all of the energy they consume; ***learning software as effective as a personal tutor***; prosthetics so advanced that you could play the piano again; an expansion of the frontiers of human knowledge about ourselves and world the around us. We can do this.”

**REMARKS BY THE U.S. PRESIDENT AT THE
NATIONAL ACADEMY OF SCIENCES ANNUAL MEETING**

National Academy of Sciences, Washington, D.C., 2009

<http://my.barackobama.com/page/community/post/amyhamblin/gGxW3n>

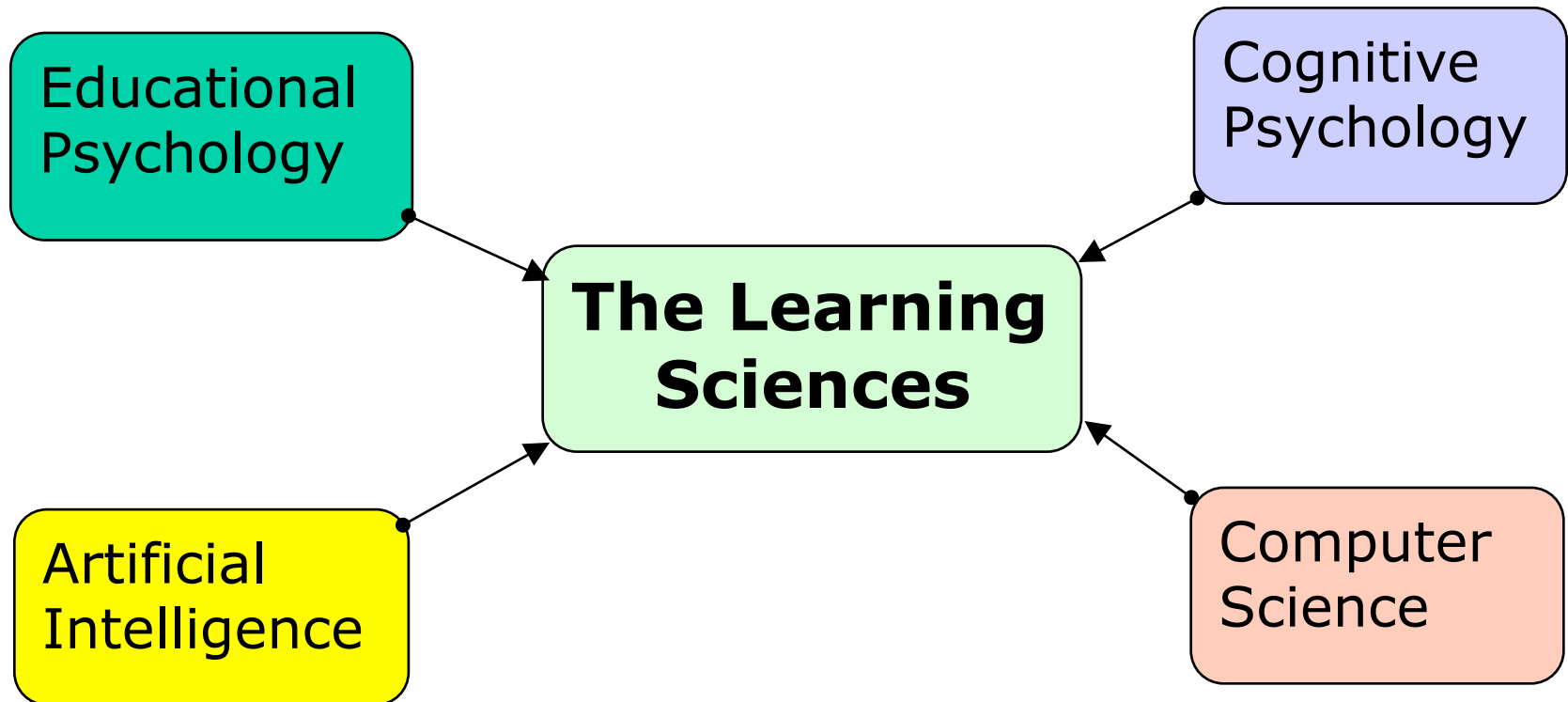
Take home message #1:

There is currently a very strong, general belief – a “gold rush”, if you will – that computers and educational software can impact learning on a large scale

YES!

So what role does / will the Learning Sciences and Advanced Technology play?

- The Learning Sciences: an interdisciplinary field to further our understanding of learning – and learning with technology



Challenges in Addressing Learning within the Learning Sciences

How to Learn?

Cognitivism vs. Constructivism

How to Conduct Research?

Rigor vs. Relevance

How to Conduct Research?

Design-Based vs. Empirical

Level of Study?

Micro vs. Intermediate vs. Macro

My Personal Take – “A Big Tent”

- **Cognitivism vs. Constructivism?**
 - Fundamental math knowledge and skills → Individual educational technology
 - Exploratory science skills, Critical thinking skills → Collaborative educational technology
 - In CSCL, there are theories and approaches (e.g., scripting) in which individual work is a precursor to (or a stage of) collaborative learning
- **Rigor vs. Relevance?**
 - Why not both? → e.g., Rigorous studies in classrooms
 - The Pittsburgh Science of Learning Center (www.learnlab.org)
- **Design-Based vs. Empirical Research?**
 - Early stage research, e.g., Exploring how students collaborate with microworlds → Design-based research
 - More mature research, with well-developed ed technology, e.g., algebra learning → Empirical research

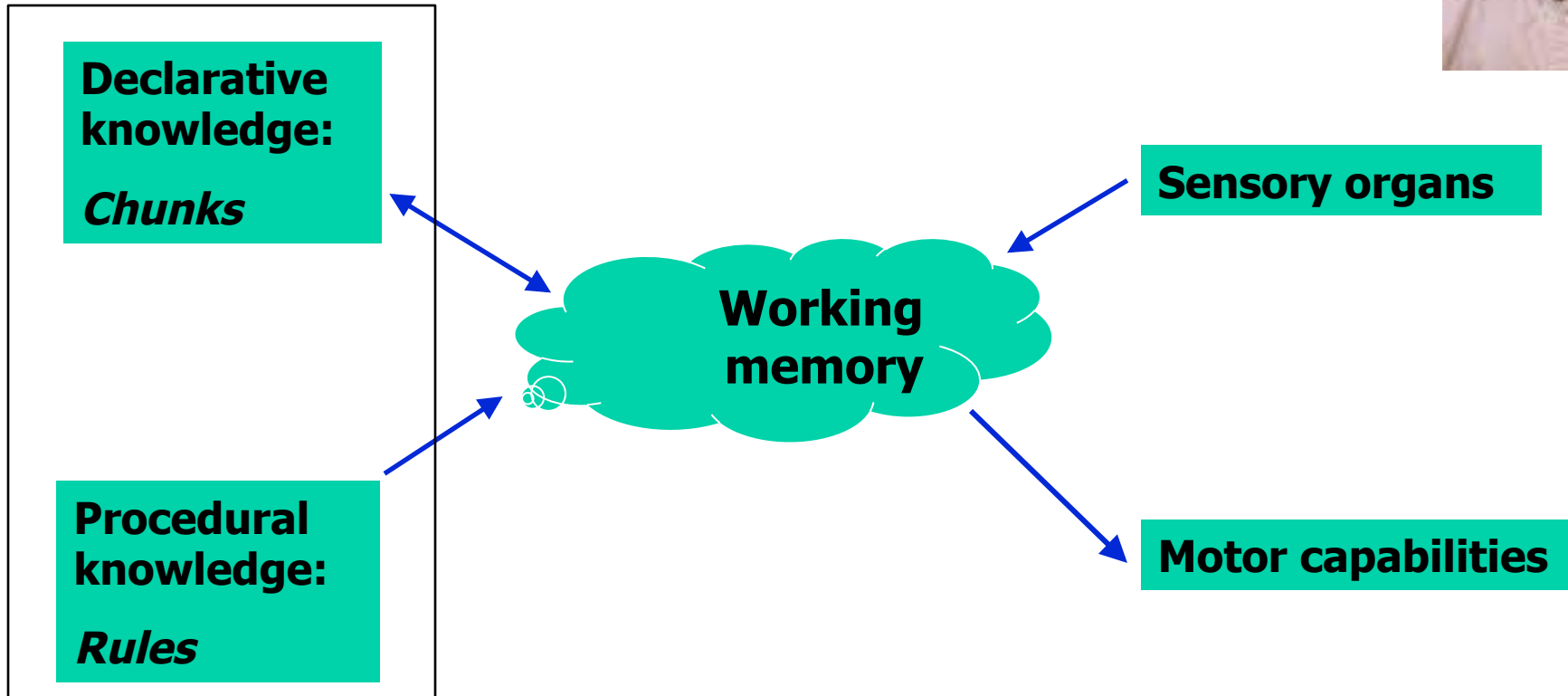


Where does it all begin?

Learning theories and instructional principles from the Learning Sciences...



ACT-R Theory - Anderson



Long term Memory

- Learning is a process of acquiring declarative knowledge, then procedural knowledge
- **Ed Tech Result:** Model-Tracing (Cognitive) Tutors

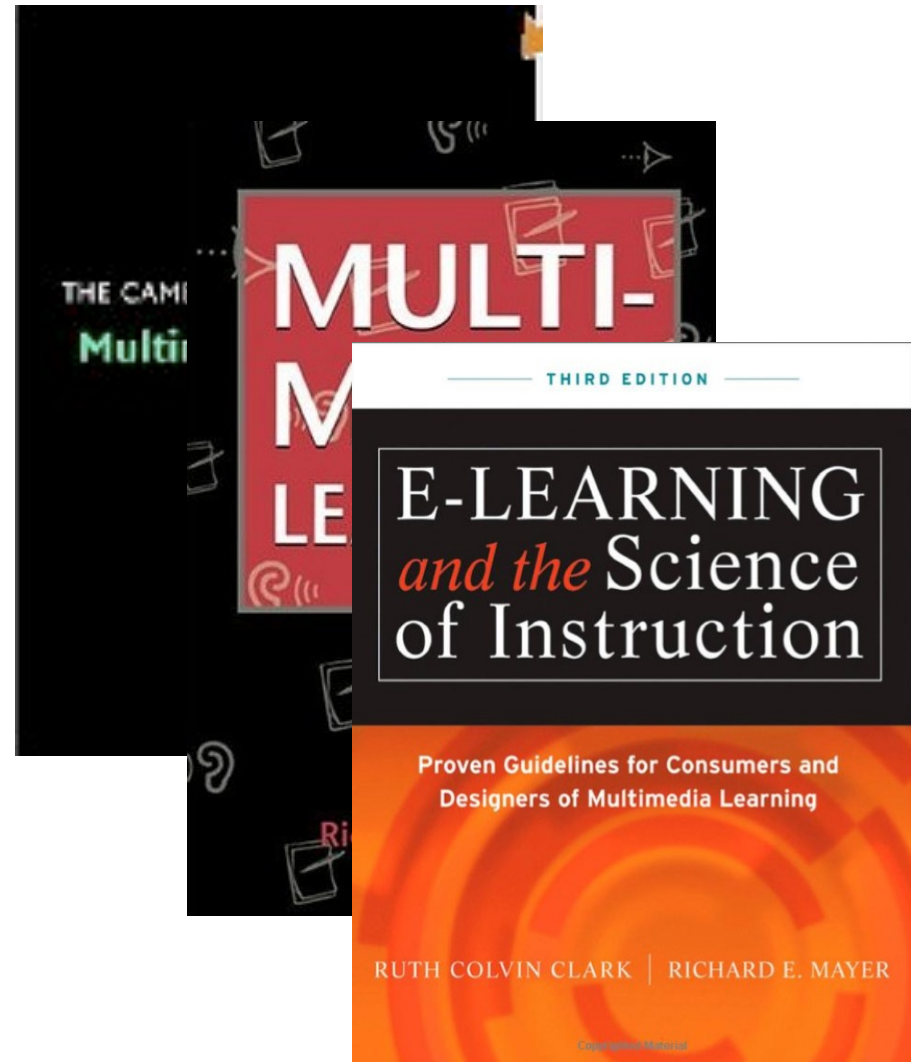
Learning from Errors - Ohlsson



- People detect their errors by comparing the outcomes of their own actions with the expected/desired outcomes
- People correct their errors by restricting the application of faulty strategies and methods → Rule specialization
- Both detection and correction are served by declarative knowledge in the form of constraints on good solutions
- ***Ed Tech Result:*** Constraint-based tutors

Multimedia Learning Principles (Richard E. Mayer)

- Principles for online learning, based on *scientific* results
 - Multimedia Principle
 - Contiguity principle
 - Modality principle
 - Redundancy principle
 - Coherence principle
 - Personalization principle
 - Politeness principle
 - Worked-examples principle



What do Multimedia Principles have to do with the Learning Sciences?

Theory

Information Delivery

Learner-centered

Starting point

Capabilities of multimedia technology

How the human mind works

Goal

“Feed” the student information

Aid to human cognition

Issues

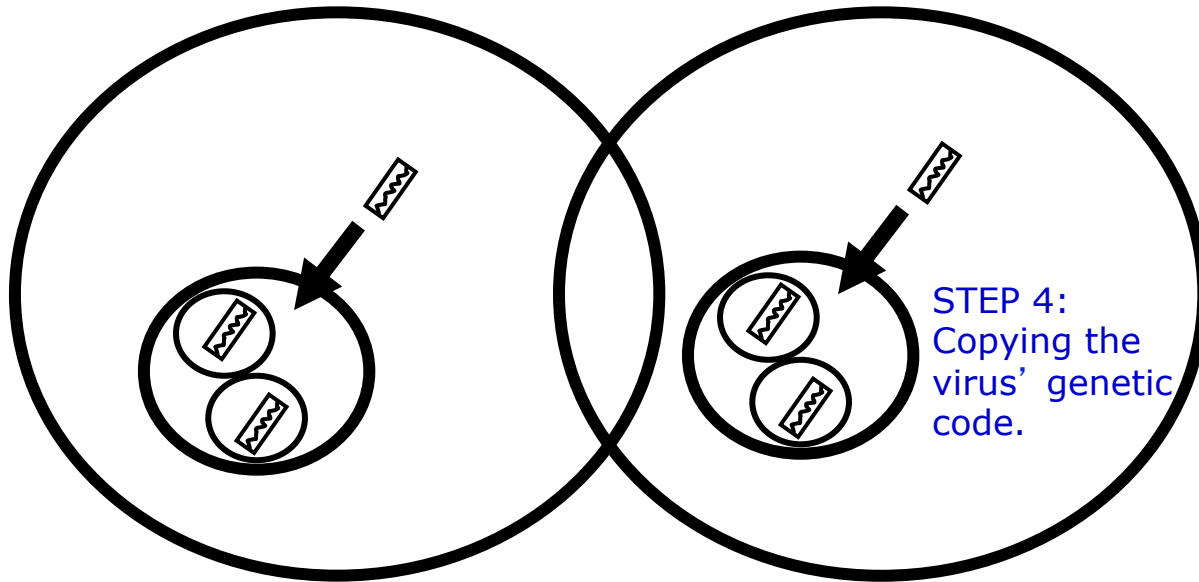
How can we use cutting-edge technology?

How can we adapt multimedia technology to aid human cognition?

Better to adapt presentation to the way the human mind works!

Example: Contiguity Principle

A not-so-good example...



STEP 4:
Copying the
virus' genetic
code.

STEP 4:
Copying the
virus' genetic
code.

A good example...

- Empirical Evidence
 - ✓ Confirmed in: 8 of 8 scientific studies
 - ✓ Median effect size: 1.11

Example: Politeness Principle

A good example...

Hint: "Let's convert the units of the first term"

Problem

#	Units	Substance		#	Units	Substance	
125	mL	solution	□		□
	□		□

A not-so-good example...

Hint: "Convert the units of the first term now!"

- Empirical Evidence
 - ✓ Confirmed in 3 Of 3 scientific studies, but primarily for low prior knowledge learners
 - ✓ We found an effect only for low prior knowledge learners!

McLaren, B.M., DeLeeuw, K.E., & Mayer, R.E. (2011). A politeness effect in learning with web-based intelligent tutors. *International Journal of Human Computer Studies*, 69(1-2), 70-79. doi:10.1016/j.ijhcs.2010.09.001.

So what about the
educational technology we've
developed?

What is the variety of educational technology in use?

- *Individual learning* – Intelligent tutoring systems (and computer-based instruction) for mathematics, science, reading, etc.
- *Collaborative learning* – Debate and argumentation systems; Joint writing exercises; joint problem solving
- *Educational games* – Math or science embedded in a video / computer game
- *Online Courses*
 - *Individual, Self-Paced Courses*: Khan Academy, Peer-to-Peer University
 - *Massive Open Online Courses (MOOCs)*: Large-scale interactive participation and open access to courses

Individual Learning: Intelligent Tutoring Systems

- Intelligent tutoring systems (ITS)
 - Automated 1:1 tutor
 - “Perfect Storm” of Educational Psychology, Cognitive Psychology, Computer Science, Artificial Intelligence

- Andes: College Physics Tutor
 - Replaces homework

- Algebra Cognitive Tutor
 - Part of complete course

- SQL-Tutor Constraint-Based Tutor
 - Central part of Addison-Wesley Course

The screenshot shows the SQL-TUTOR interface. At the top, there are navigation buttons: Change Database, New Problem, History, Student Model, Run Query, Help, and Log Out. The main area is divided into two columns. The left column contains a form for writing a SQL query. The right column shows the feedback for a submitted query.

Problem 30
List the titles and numbers of all movies that have won at least one Academy Award and have been made in or after 1988.

SELECT title, number
FROM movies
WHERE aawon>1 and year>=1988

Feedback: Almost there - a few mistakes though. One of them is in the FROM clause. You can correct your query and press 'Submit' again, or try getting some more feedback. Would you like to have another go?

Tutor: feedback on submitted answer; constrained by possible correct queries

Schema for the MOVIES Database

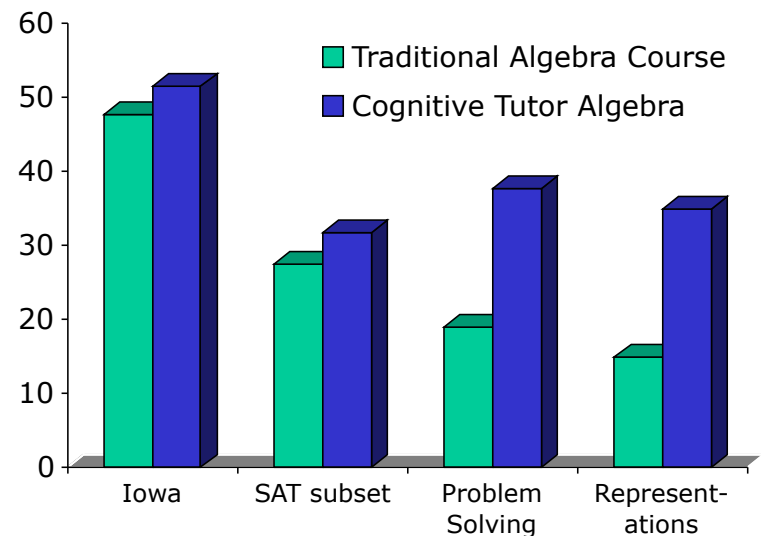
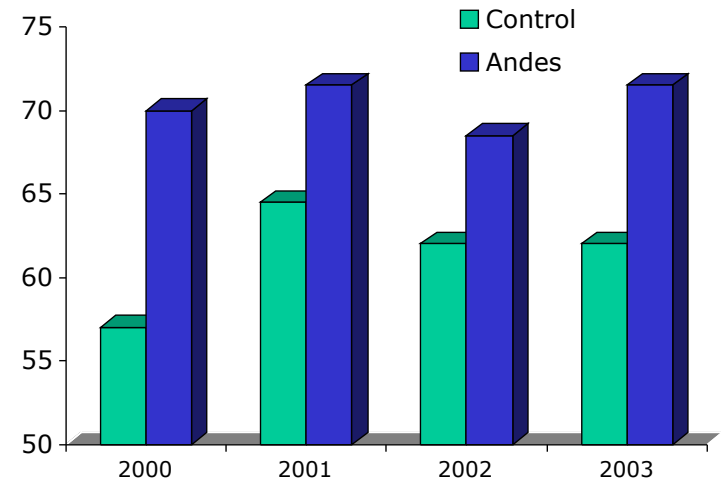
The general description of the database is available [here](#). Clicking on the name of a table brings up the table details. Primary keys in the attribute list are underlined, foreign keys are in *italics*.

Table Name	Attribute List
<u>DIRECTOR</u>	<u>number</u> lname fname born died
<u>MOVIE</u>	<u>number</u> title type aanom aawon year critics <i>director</i>
<u>STAR</u>	lname fname <u>number</u> born died city
<u>CUSTOMER</u>	lname fname <u>number</u> address rentals bonus jdate
<u>TAPE</u>	<u>code</u> <i>movie</i> pdate times <i>customer</i> hiredate
<u>STARS_IN</u>	<i>movie</i> <i>star</i> role

Individual Learning: Intelligent Tutoring Systems

Model-Tracing Tutors (VanLehn, Koedinger)

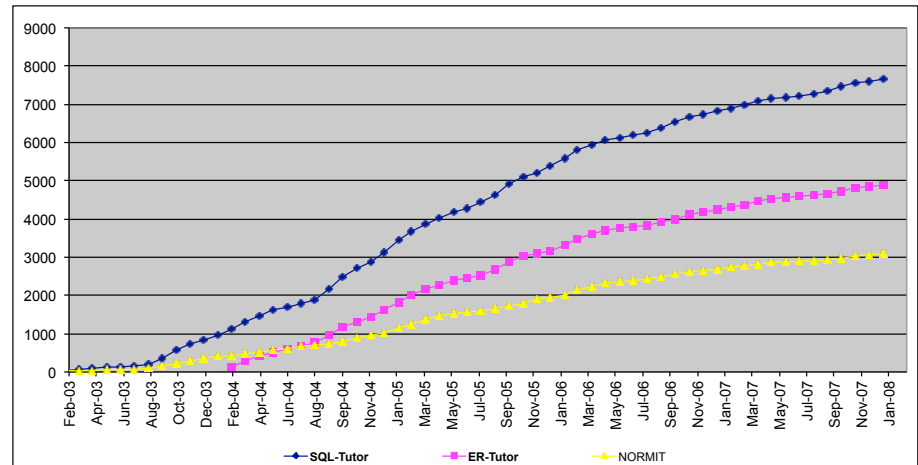
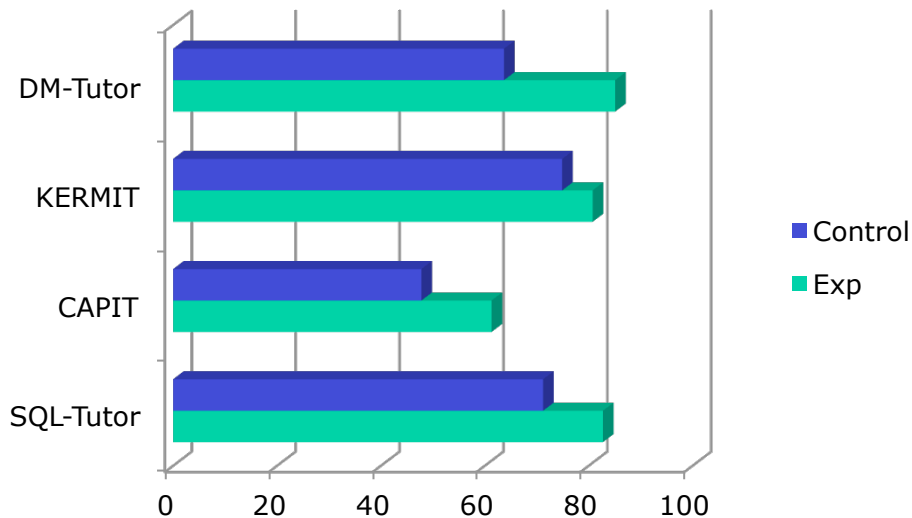
- Andes: College Physics Tutor
 - Field studies: Significant improvements in student learning
- Algebra Cognitive Tutor
 - 10+ full year field studies: improvements on problem solving, concepts, basic skills
 - 50-100% better on problem solving & representation use
 - 15-25% better on standardized tests
 - Regularly used in *1000s of schools* by *100,000s of students!*



Individual Learning: Intelligent Tutoring Systems

Constraint-based Tutors (Mitrovic et al)

- SQL-Tutor: 16 studies since 1998; KERMIT/EER-Tutor: 13 studies since 2001
- Significant improvements in learning compared to the classroom control; Graph shows 4 such studies, with median effect size of 0.88
- Improvement on problem solving, conceptual knowledge, and meta-cognitive skills
- Database tutors used regularly at the University of Canterbury and also on the DatabasePlace Web portal



Individual Learning: Intelligent Tutoring Systems

- There are other intelligent tutoring systems with positive and highly encouraging learning results, e.g., AutoTutor (Graesser et al), iStart (McNamara et al), the Reading Tutor (Mostow et al)
- Can tutors be developed to identify and react to affect (e.g., boredom, frustration and confusion)? (e.g., Robison et al, 2009; Craig et al, 2004; Kapoor et al, 2001)
 - How to identify affect?
 - Video, sensors (less practical)
 - Student actions (more practical)
 - Automatically adjust intelligent tutoring strategy based on affect states

Individual Learning: Intelligent Tutoring Systems

Acceptance / Hype?

- Well established and accepted, (relatively) widely used

Scientific Support?

- Strong empirical basis

Level of Technical Sophistication?

- Medium-Low: production rules, constraints, basic AI techniques are standard; language techniques more sophisticated

Issues to Address?

- How to deal with affect?
- How to keep students engaged and stay relevant in an age of game playing and social networking?

Collaborative Learning: CSCL Systems

- Builds on the concept of *constructivism*; students develop their own understanding
- Groups share and construct knowledge
- Computers and software are used as the means of communication or as a common resource

CSILE (Scardamalia and Bereiter)

LASAD (Loll et al)

VMT-Basilica (Kumar et al)

Students & Tutor working on designing a power plant

Tutor discusses thermodynamics concepts and makes arguments for design alternatives.

Students share results and ideas in a common workspace

Collaborative Learning: CSCL Systems

- The interaction is what matters in CSCL scenarios!
 - Not enough to measure the outcome (e.g. posttest results, learning gains)
 - Need to analyze the *interaction processes*
- Much more design-based research
- How to guide student interaction?
 - Knowledge representations (Suthers et al, 2003)
 - Collaboration scripts: predefined phases, roles (Dillenbourg, 2002; Weinberger, 2011)
 - Adaptive scripting (AI, natural language processing)
 - Automatically assess dialog and interactions (but rare)
- This is hard! Not always clear, empirical learning results

Collaborative Learning: CSCL Systems

The screenshot displays a CSCL system interface. On the left, a portrait of a man is visible. The main area shows an argumentation diagram with several nodes connected by green arrows. The nodes are:

- 11 - Hauptargument:** IL haben vom CO2 Ausstoß profitiert. Quelle: Brown
- 2 - Hauptthese:** Drastische CO2-Einsparungen der entwickelten Welt sind eine moralische Pflicht. Quelle: Brown
- 10 - Hauptargument:** Industrieländer als Hauptverantwortliche der Emissionen; 10-fach höherer Anteil. Quelle: Brown
- 17 - Hauptargument:** Verteilungsgerechtigkeit: Verursacher muss auch die Lasten für die Beseitigung schaffen. Quelle: Brown
- 4 - Hauptthese:** Argumente gegen drastische Nutzen-Analysen basieren, Quelle: Bro
- 36 - Fakt:** mit nur 4,6 % der WBV haben die USA 23% der weltweiten Emissionen verursacht. Quelle: Brown
- 39 - Fakt:** Hinsichtlich der Ansammlung von CO2 in der Atmosphäre: ILn haben einen zehnfach größeren Anteil als EL. Quelle: Brown
- 8 - Hauptargument:** katastrophale Folgen & Tod vieler Menschen, wie z.B. durch Krankheiten, Unwetter, Nahrungsmittelknappheit, Trinkwassermangel. Quelle: Brown
- 14 - Hauptargument:** Kosten und Nutzen kann nicht auf das "eigenes" Land bezogen werden, da andere Länder am meisten davon profitieren und dabei nicht als Verursacher gelten. Quelle: Brown

On the right, there is a sidebar with a 'Hilfsmittel' section, a 'Chat' window, and a 'Fürsprecher' section. The chat window shows a conversation:

Chat

(11:45:37) a-2R: Was hältst du von dem Vorschlag in Box 21? Dass alle Länder einen gewissen Anteil ihres Bruttoeinkommens in Forschung und Entwicklung stecken?

(11:49:26) a-2L: Aber sollten nicht die IL mehr investieren?

(11:50:13) a-2R: Aber dann wäre es kein gerechter Ansatz mehr, nachdem alle gleichviel zusteuern müssen.

(11:51:59) a-2L: *Dagegen spricht* dass die IL ja auch mehr Emissionen verursacht haben und somit mehr Verantwortung tragen und auch von dem CO2 Ausstoß profitiert haben, siehe Hauptargument 11

(11:52:13) a-2L: und 17

(11:55:03) a-2R: *Dagegen spricht* dass die IL ja mehr investieren würden als

Below the chat, there is a 'Bitte wähle einen Satzanfang ...' section with a text input field and 'Senden' and 'Löschen' buttons. The 'Fürsprecher' section has a table:

Fürsprecher	Konstruktiver Kritiker
Ein zentraler Punkt ist	Ich würde das anders formulieren:
Dafür spricht	Dagegen spricht
Zum Beispiel	Aber
Laut einer Statistik / Schätzung	Hast Du dafür (weitere) Belege
Hast Du Fragen bzgl	Kannst Du mir erklären

1. Analyze argumentation texts by creating an argumentation diagram

2. Discuss diagrams with learning partner using sentence openers



Scheuer, O., McLaren, B. M., Weinberger, A., & Niebuhr, S. (2013). Promoting critical, elaborative discussions through a collaboration script and argument maps. *Instructional Science*, 41(3) May 2013. doi: 10.1007/s11251-013-9274-5.

Collaborative Learning: CSCL Systems

Conversational Agents (Rosé et al)

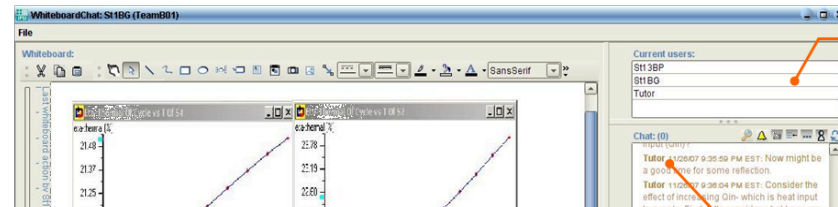


- Use of natural language processing (NLP) and discourse theory to guide collaborative process
- Conversational agents are aimed at **shaping conversation** and **supporting effective participation in conversation** to achieve positive impact on **learning**

VMT-Basilica

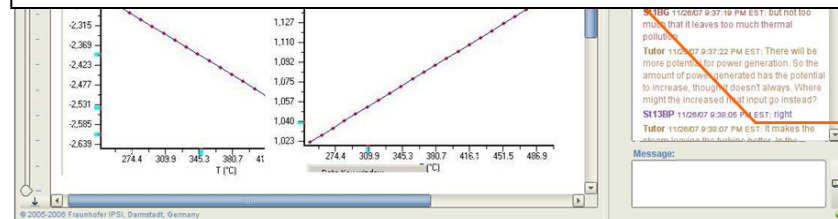
- Historical Perspective:

- Socratic dialogue tutors (Rosé et al, 2001)
- Students learn more when working with a partner, and even better with support (Gweon et al, 2006)
- Tutorial dialogue agents provide effective support for collaborative learning (Kumar et al, 2007)



Students & Tutor working on designing a power plant

**** Students learn up to 1.25 standard deviations more when interactive support is provided in the environment. (more than a full letter grade!)**



Students share results and ideas in a common workspace

Collaborative Learning: CSCL Systems

Acceptance / Hype?

- Reasonably established; some real use

Scientific Support?

- Lots of design-based research; Some empirical basis

Level of Technical Sophistication?

- Wide range:
 - Low-tech: Straightforward scripting approaches
 - High-tech: Conversational agents

Issues to Address?

- Better understanding of human interaction – What is optimal, what is suboptimal?
- How to automatically intervene with student interactions?

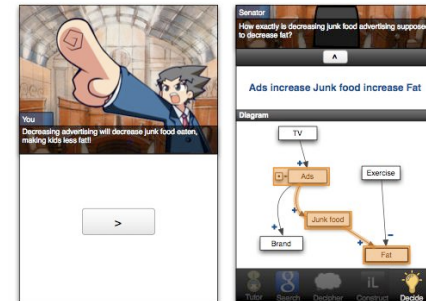
Educational Games

- Students spend much more time out of school than in school ...
- ... and much of it playing video games!
 - Boys play video games 13 hrs/wk; Girls 5 hrs/wk (Gentile et al, 2004)
- What if even a small portion of this time was devoted to *educational* games?

Zombie Division (Habgood et al)



Policy World (Easterday)



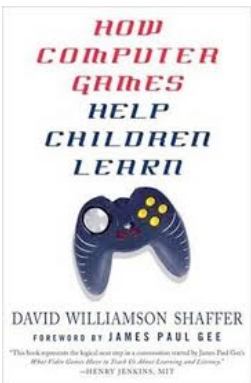
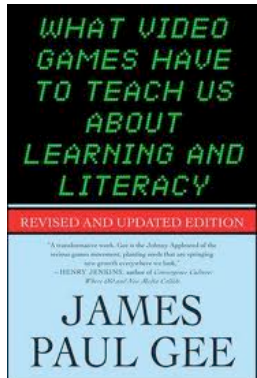
Learning Intercultural Negotiation with Virtual Characters (Ogan)



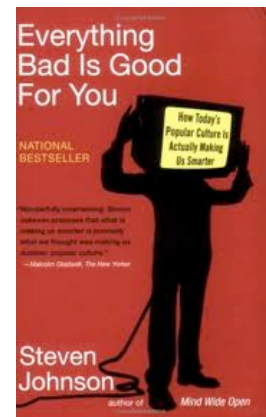
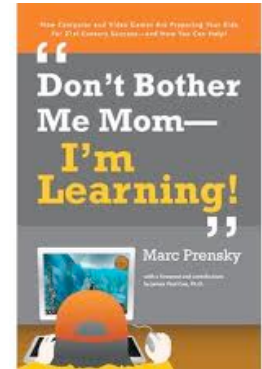
Civilization (Meier)



Educational Games



- Video games are the best-designed learning environments that we have today (Gee, 2003)
- Games teach 21st-century skills (Prensky, 2006)
- Games can help students engage in meaningful learning (Shafer, 2006)
- Video games make us smarter - partly responsible for rise in IQ scores (Johnson, 2005)



“It has become clear from reading the games literature that there is considerably more enthusiasm for describing the affordance of games and their motivating properties than for conducting research to demonstrate that these affordances are used to attain instructional aims, or to resolve problems found in prior research.”

Tobias & Fletcher, 2011

Educational Games

E.g., *Zombie Division*



Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating Children to Learn Effectively: Exploring the Value of Intrinsic Integration in Educational Games. *Journal of the Learning Sciences*.

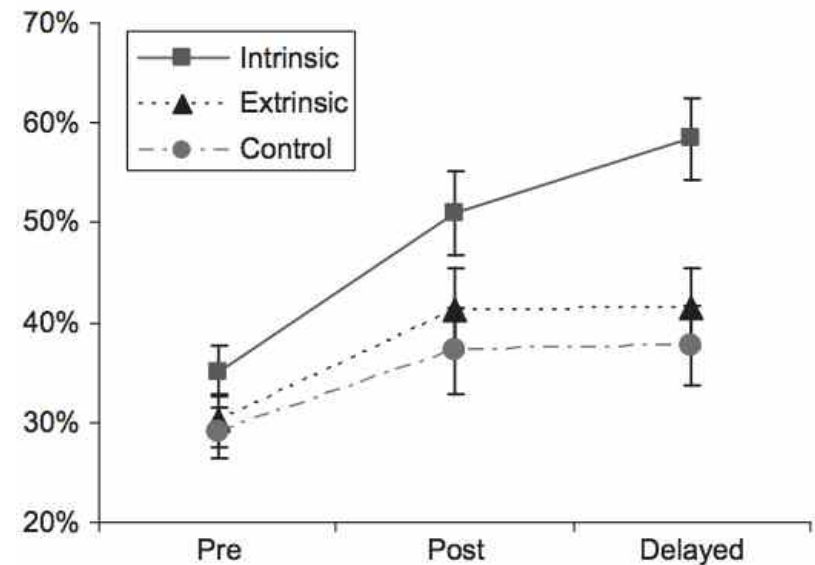
- 3D action-adventure game
- Designed to support learning of whole number division
- Zombies succumb when attacked with weapon whose number divides the Zombie's number evenly
- Mathematics is integrated into game's core mechanic

Educational Games

Zombie Division Results – Study



Results



Mean percentage score by time and game condition.

- Study 1: Compared 3 groups using 3 versions of the game:
 - Intrinsic: Division as part of the game (20 kids)
 - Extrinsic: Division as separate step (between levels) of the game (20 kids)
 - Control: No division in the game (18 kids)

Other Empirical Results

- Squire, 2004
 - ✓ *Civilization*: Used case study analysis, found the use of a game for learning world history engaging to students
- Johnson & Mayer, 2010
 - ✓ *Electrical Circuits Ed Game*: Found that students learned more in the game when they only had to explain steps by selecting explanations, rather than typing them
- Chase, 2012
 - ✓ *Genetics Ed Game*: Found that (some) students learned more and had more persistence when they played a version with an element of chance (i.e., more “game-like”)
- By and large, though, these were small, focused, and unreplicated studies -> The jury is still out!

Acceptance / Hype?

- Lots of use, Lots of hype

Scientific Support?

- Not much empirical support

Level of Technical Sophistication?

- Graphically sophisticated; some AI

Issues to Address?

- More empirical investigation and evidence!
- Learning Science questions:
 - Balance between motivation and focus on learning?



- Free archive of “snappy” instructional videos
- Khan: “the world's first free, world-class virtual school where anyone can learn anything”
- Focus on “micro lectures”, over 4,000, on topics including mathematics, history, economics, computer science, and many more
- Not-for-profit organization, with significant backing from the Bill & Melinda Gates Foundation and Google
- Courseware has gotten more than 257 million total views, compared to MIT’s OpenCourseWare’s (OCW) 50 million

Online Courses: Individual, Self-Paced Courses – The Evidence

- Much of the evidence is anecdotal for online & Khan
- However, the U.S. Department of Education published a 2010 meta-analysis for the period 1996-2008:
 - Screened for studies that:
 1. Contrasted online learning with F2F learning
 2. Measured student learning outcomes
 3. Used a rigorous research design
 4. Enough information to calculate an effect size
 - Only 50 studies qualified; Mostly medical training, higher ed
 - *Results:*
 - Modest benefit for online learning vs. F2F learning
 - Benefit higher for *blended* online/F2F vs. F2F learning
 - BUT online and blended typically involved extra learning time
 - Hard to generalize to K-12, given different target

“Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies” (2010). U.S. Department of Education,

<http://www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf>

Online Courses: MOOCs

- Huge Hype in 2012 – “the year of the MOOC”
 - Emergence of well-financed providers, connected to universities: Coursera, Udacity, edX
 - Dozens of universities in North America, Europe, and Asia have announced partnerships with MOOC providers
- Large-scale, socially networked, and free participation via the web
- “Connectivism” – Emphasizes the role of the social and cultural, rather than the individual, in learning
- Use of technology – not too advanced but a lot of it
 - Crowd sourcing for peer review and/or group collaboration
 - Automated feedback on online assessments
- Very low completion rates (< 10%, data from Coursera)

Online Courses: MOOCs – The Evidence

- Recent rise of MOOCs provides millions of students with access to lectures, online forums and other educational materials → but it's been difficult so far to gauge the learning
- Some MOOCs apply theories of instruction and standards of effective online education – and some do not
- Bottom Line: It's too early to tell what the impact of MOOCs will be

Acceptance / Hype?

- Dramatically growing use; Lots of hype

Scientific Support?

- Not much empirical support; for MOOCs too early for serious research

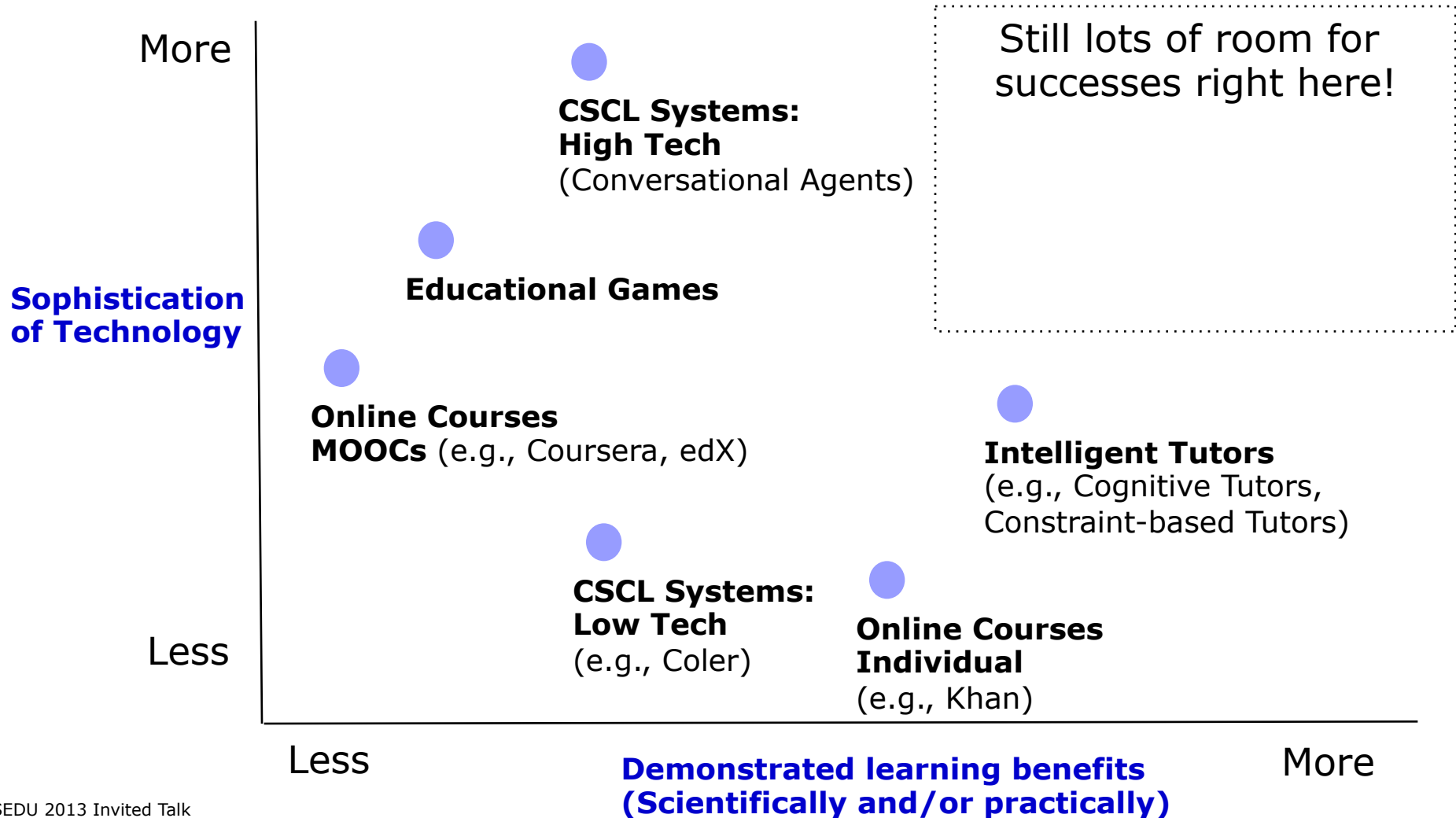
Level of Technical Sophistication?

- Some interesting collaborative technology; significant technical infrastructure required

Issues to Address?

- Need more empirical investigation and evidence!
- Learning Science questions:
 - Can online courses really match learning in F2F courses?
 - How can we evaluate effectiveness with selection effect?
 - How can online courses take advantage of multi-modalities?

How are we doing with respect to the science of educational technology?

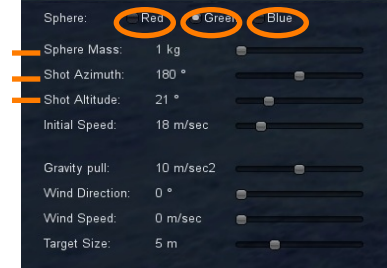
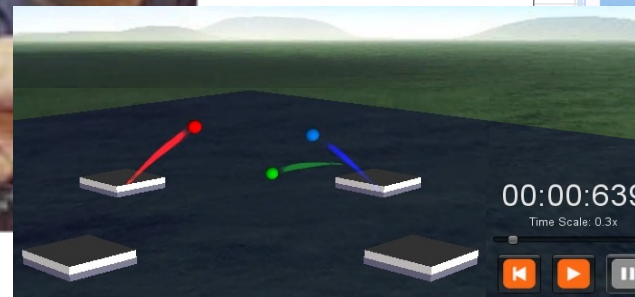
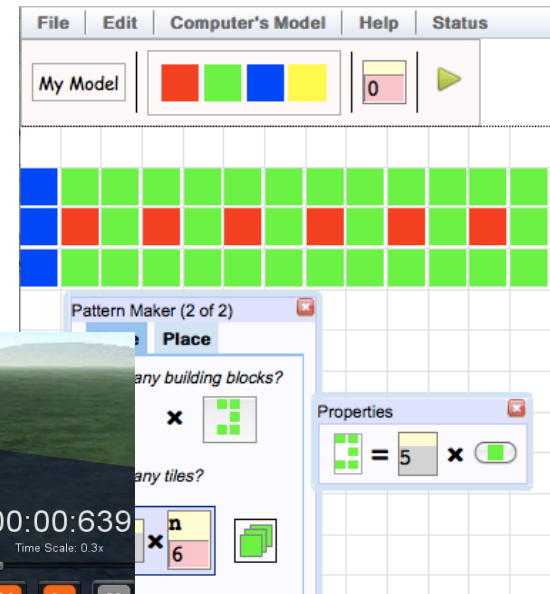


Other Examples of Educational Software: Simulations and Microworlds

Virtual Lab – For chemistry
(Yaron et al, 2003)



eXpresser – For math
(Mavrikis et al, 2012)



3-D Juggler (Kynigos, 2007)

Educational Data Mining and Learning Analytics: A Way to Improve Educational Software

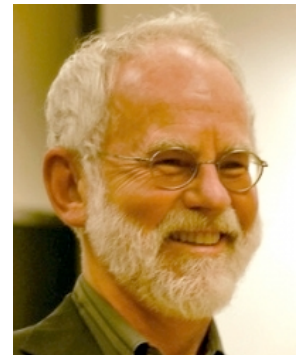
- What do we do with all that data?
 - Online courses, Intelligent Tutors, generating mountains of data
- Educational Data Mining – Use of AI, in particular machine learning, and statistical analyses to assess patterns of student learning to:
 - Build better educational software
 - Develop techniques to identify patterns in real-time and intervene in learning sessions (e.g., “gaming the system”)
 - Better analyze instructional technologies for scientific purposes
- www.educationaldatamining.org

Conclusions

- Learning science is definitely being brought to bear to:
 - Guide the development of educational software
 - Validate and evaluate educational software
 - Improve educational software
- Yet, more science and technology is needed:
 - How can we identify and respond to boredom, frustration and confusion in tutoring systems?
 - Educational games are exciting, but are they beneficial to learning?
 - Same issue with MOOCs → Lots of hype but do they really benefit learning?

Conclusions

- Finally, why not combine educational technologies?
 - Intelligent tutors and Individual online courses → Being done to a certain extent with CMU's Open Learning Initiative
 - CSCL and educational games → A natural synergy
 - Educational data mining / Learning Analytics to improve MOOCs → Stanford's Roy Pea & colleagues are doing just this



Take home message #2:

The Learning Sciences, as well as researchers and developers of advanced technology, have the scientific principles and approach to verify the gold rush *and* to help educational software succeed

YES!

Questions?



Special thanks to the following colleagues, who have been great colleagues (and whose slides I borrowed):

Rich Mayer, Vincent Aleven, Tanja Mitrovic, Carolyn Rosé,
Ken Koedinger, Ryan Baker, Oliver Scheuer