



Institute for Intelligent Systems  
THE UNIVERSITY OF MEMPHIS



# Improving Comprehension Strategies of Struggling Adult Readers through Conversational Dialogues with AutoTutor

## Art Graesser



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EDUCATION SCIENCES



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# Overview

- **Conversational Agents in Learning Environments**
- **Dialogues, Trialogues, and N-logs**
- **AutoTutor Trialogues to Help Struggling Adult Readers**

# Why focus on adults with low literacy?

- 1 out of 6 adults in the US do not read well enough for them to get a decent job (National Research Council, 2011; Programme for International Assessment of Adult Competencies, OECD, 2011).
- Attendance is a problem because work schedules, childcare issues, and transportation difficulties (Greenberg, Reder, Rosen).
- Comprehension training interventions for adult readers are few in number, with weak evidence they are helpful (Greenberg, Mellard, Sabatini).
- **AI technology can come to the rescue by improving comprehension training and providing intelligent support, 24-7!**

Graesser, A.C., Greenberg, D., Olney, A.M., & Lovett, M.W. (in press). Educational technologies that support reading comprehension for adults who have low literacy skills. In D. Perin (Ed). *Wiley adult literacy handbook* . New York: Wiley.

# Organizations committed to improve adult literacy

Commission on Adult Basic Education: <http://www.coabe.org/>

Institute of Education Sciences: <http://ies.ed.gov/>

Literacy Information and Communication System: <http://lincs.ed.gov/>

Office of Career, Technical, and Adult Education:  
<http://www2.ed.gov/about/offices/list/ovae/index.html>

ProLiteracy: <http://www.proliteracy.org/>

VALUEUSA: <http://www.valueusa.org/>

**Daphne Greenberg**

**Jan Frijters**

**Art Graesser**

**Maureen Lovett**

**Lee Branum-Martin**

**Andrew Olney**



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The research reported here is supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305C120001 Georgia State University. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.

# Conversational Agents in Learning Environments

- Graesser, A.C., Rus, V., Hu, X. (2017). Instruction based on tutoring. In R.E. Mayer and P.A. Alexander (Eds.), *Handbook of Research on Learning and Instruction* (pp. 460-482). New York: Routledge Press.
- Nye, B.D., Graesser, A.C., & Hu, X. (2014). AutoTutor and family: A review of 17 years of natural language tutoring. *International Journal of Artificial Intelligence in Education*, 24, 427-469.

# Adaptive Intelligent Conversational Agents



**STEVE**



**AutoTutor Trialogs**



**AutoTutor Trialogs  
with ALEKS algebra**



**Tactical Language and  
Culture System**



**Guru (biology)**



**iSTART (reading)**



**DeepTutor (physics)**



**Betty's Brain**



**Herman-the-Bug**



**Mission Rehearsal**

# Memphis Intelligent Conversational Agents



**AutoTutor**  
(computer literacy)



**AutoTutor** (reading  
comprehension)



**ARIES** (scientific  
reasoning)



**ElectronixTutor**



**Guru** (biology)



**AutoTutor** (with  
ALEKS algebra)



**HURA Advisor**  
(research ethics)



**Personal Assistant for  
Lifelong Learning (PAL3)**



**DeepTutor** (physics)



# Functions of Conversational Agents

- **Help when initiated by the user**
- **Navigational guide**
- **Modeling action, thought, and social interaction**
- **Adaptive intelligent conversational dialog**
- **Staging arguments to prompt deeper learning**
- **Staging scenarios for assessment**
- **Many roles: peers, tutor, mentor**

# Emotions During Learning

(Graesser, Baker, Craig, D'Mello, Lehman, Rodrigo)

**Boredom**  
(23%)



**Confusion**  
(25%)



**Delight**  
(4%)



**Flow**  
(28%)



**Frustration**  
(16%)



**Surprise**  
(4%)

# Measures collected at different grain sizes

- 1) **Lessons** attempted and completed
- 2) **Performance in each lesson**
- 3) **Selecting answers** to multiple choice questions
- 4) **Semantic matches** between natural language input and expectations or misconceptions
- 5) **Initiative** by asking questions, selecting tasks, and performing unprompted actions
- 6) **Fluency** of language and action
- 7) **Engagement** by response time patterns & coupling with item difficulty
- 8) **Emotions** (confusion, frustration, boredom, etc.)

# Meta-analyses on Intelligent Tutoring Systems

		Effect Size
Kulik & Fletcher (2016)	50 comparisons	0.66
VanLehn (2011)	54 comparisons, STEM	0.58
Ma, Adesope, Nesbit, & Liu (2014)	107 comparisons	0.43
Steenbergen-Hu & Cooper (2014)	39 comparisons, college	0.35
Steenbergen-Hu & Cooper (2013)	26 comparisons, math, K12	0.05
Ritter, Kulikowich, Lei, et al. 2007)	Cognitive Tutor, math, WWCH	0.38
Fletcher & Morrison (2012)	Digital Tutor (1-study, N = 26)	3.17
Nye, Graesser, & Hu (2014), Graesser (2016)	AutoTutor (science, dozens of studies)	0.60 to 0.80

# Generalized Intelligent Framework for Tutoring

Army Research Lab and University of Memphis

[www.gifttutoring.org](http://www.gifttutoring.org)

Sottolare, R., Graesser, A., Hu, X., & XXXX (2013-2018). *Design Recommendations for Intelligent Tutoring Systems.*

- Learner modeling (2013)
- Instructional strategies (2014)
- Authoring tools (2015)
- Domain knowledge (2016)
- Assessment (2017)
- Teams (2018)
- Self-improving systems (2019)



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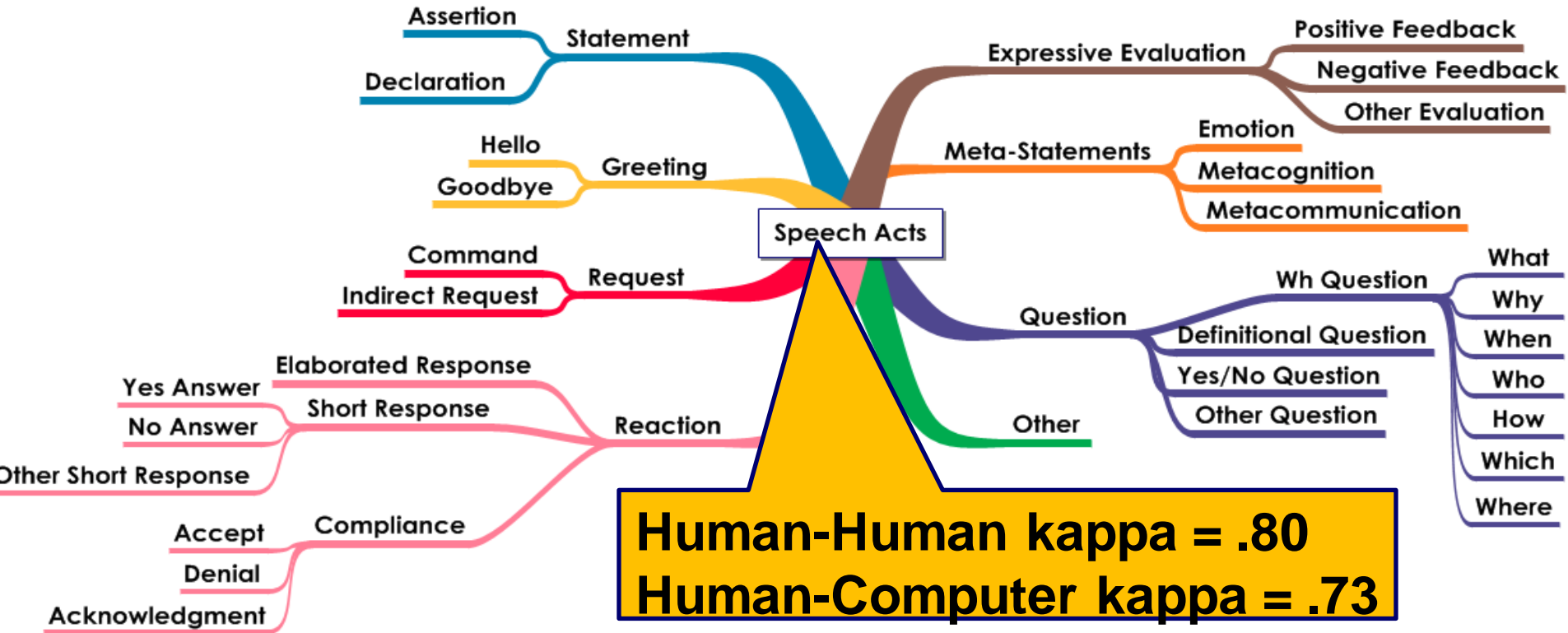
# Dialogues and Trialogues

- Graesser, A.C. (2016). Conversations with AutoTutor help students learn. *International Journal of Artificial Intelligence in Education*, 26.124-132.
- Graesser, A.C., Forsyth, C., & Lehman, B. (2017). Two heads are better than one: Learning from agents in conversational trialogues. *Teachers College Record*, 119, 1-20.

# Expectation & Misconception-Tailored Dialog

- Tutor asks question that requires explanatory reasoning
- Student answers with fragments of information, distributed over multiple turns
- Tutor analyzes the fragments of the explanation
  - *Compares to a list of expected good idea units (via LSA and Regular expressions)*
  - *Compares to a list of expected errors and misconceptions*
- Tutor posts goals & performs dialog acts to improve explanation
  - *Fills in missing expected good idea units (one at a time)*
  - *Corrects expected errors & misconceptions (immediately)*
- Tutor handles periodic sub-dialogues
  - *Student questions*
  - *Student meta-communicative acts (e.g., What did you say?)*

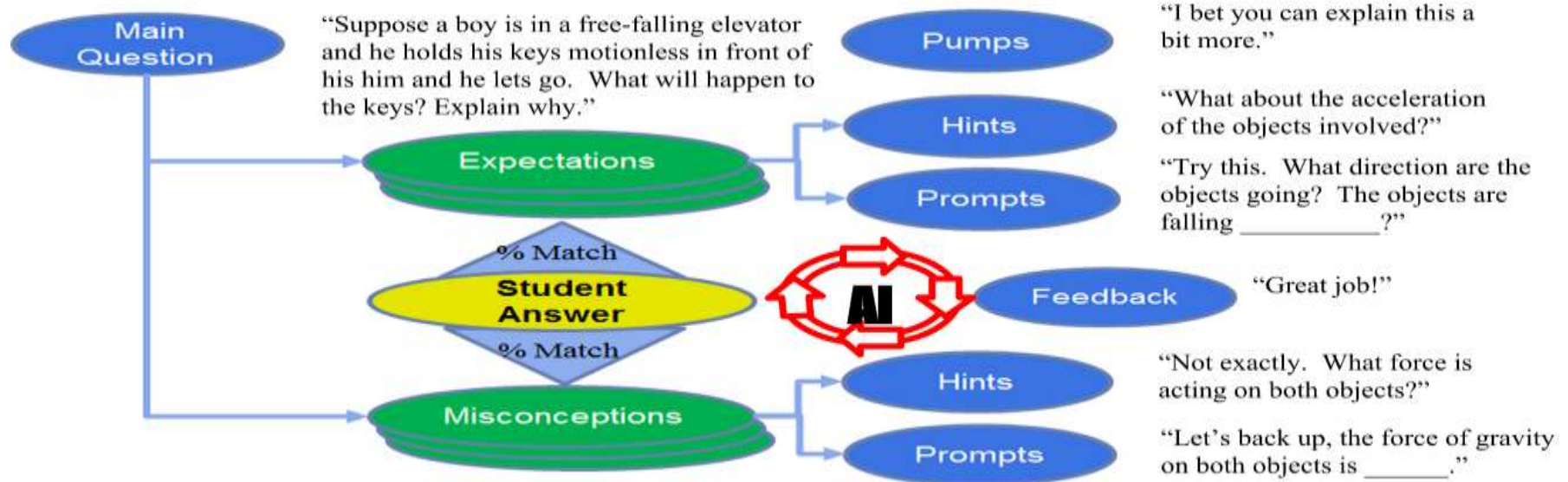
# Speech Act Hierarchy





# AutoTutor-Style (EMT) Dialog

## Dialog with student cover expectations & correct misconceptions



# Managing One AutoTutor Turn

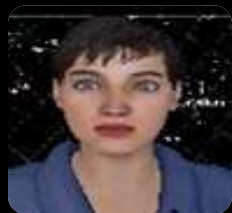
- Short feedback on the student's previous turn
  - Positive feedback: **“Yeah” “Right!”**
  - Neutral feedback: **“Okay” “Uh huh”**
  - Negative feedback: **“No” “Not quite”**
- Advance the dialog by one or more dialog moves that are connected by discourse markers
- End turn with a signal that transfers the floor to the student
  - Question
  - Prompting hand gesture
  - Head/gaze signal

# Challenges

- **Semantic matches are pretty good but not perfect →  
Understanding is limited**
- **Semantic blur between expectations and misconceptions →  
Some errors in feedback**
- **Learners expect full credit when they express a couple of juicy words instead of a sufficiently articulated statement →  
This can be irritation or frustration**
- **High verbal or knowledgeable learners read printed conversation faster than listening to an agent**
- **Limited ability to handle student questions and requests**

# Adaptive Trialogues

Expert



Vicarious

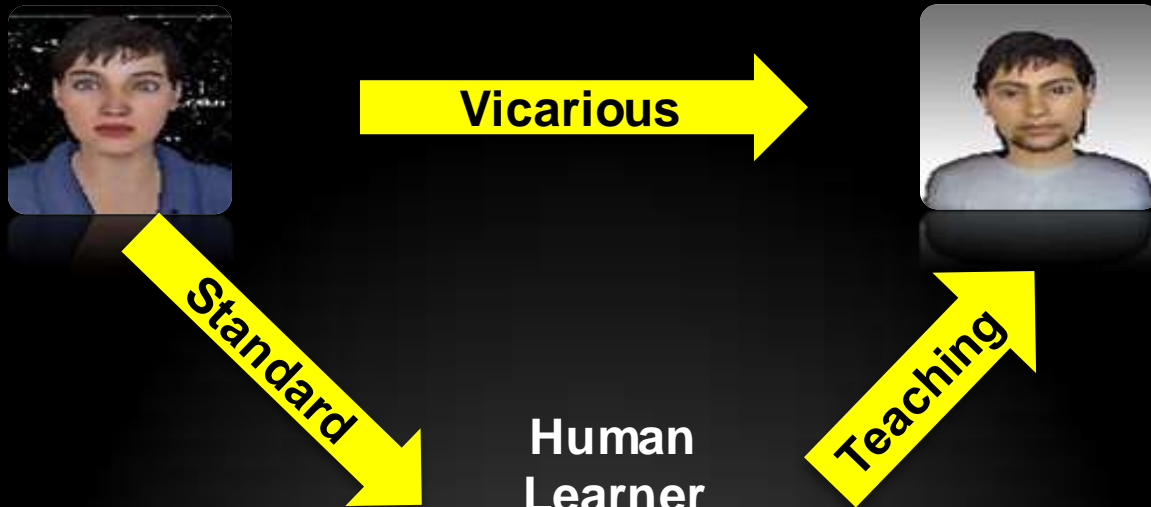
Fellow Student



Standard

Human  
Learner

Teaching

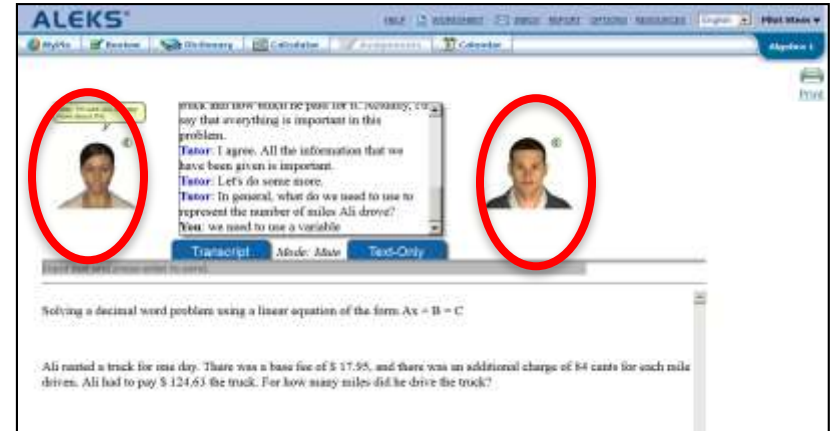


# Dialogues in Literacy and Numeracy

Xiange Hu, *University of Memphis*



Text Signals	Writer's Purpose	Using Clues	Mixed Review
100	100	100	100
200	200	200	200
300	300	300	300
400	400	400	400



**ALEKS**

truck user know "what the price for it," "quantity," "to pay that everything is important in this problem."

Tutor: I agree. All the information that we have been given is important.

Tutor: Let's do some more.

Tutor: In general, what do we need to use to represent the number of miles Ali drove?

You: we need to use a variable

Transcript: Audio: Math Text-Only

Solving a decimal word problem using a linear equation of the form  $Ax + B = C$

Ali rented a truck for one day. There was a base fee of \$ 17.95, and there was an additional charge of 84 cents for each mile driven. Ali had to pay \$ 124.63 for the truck. For how many miles did he drive the truck?



# Advantages of Trialogues

- **Two agents can model desired social interactions**
- **Two agents can disagree, stage an argument, and create cognitive disequilibrium**
- **A peer agent can echo a learner's contribution in a well articulated language, so:**
  - **Agent gets blame for a bad answer**
  - **Agent and learner gets credit for a good answer**
  - **Learner sees a well articulated response.**
- **Peer agent model good inquiry and receive good responses from the tutor agent**



# Annenberg Library

<EXIT>

Library Hours: 8am - 6pm (Mon - Fri.)  
9am - 1pm (Sat.) Closed (Sun.)

Notice for library users

1. Bring your student ID to the library.
2. No food or drink is allowed in the library.
3. Please keep quiet in the library.
4. Put books back where you find them when you are finished with the books.
5. You can check out up to two books.
6. You can keep the books for one week.



# Dialogue (English Language Skills)

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Agent	Utterance
<b>Lisa:</b>	Hey, Ron, you need to leave your water outside. I'm going to go talk to my friends. I'll see you guys inside.
<b>Ron:</b>	Why did she tell me I have to leave my water outside, Tim?
<b>Human (Tim):</b>	I don't know.
<b>Ron:</b>	Tim, why can't I drink water?
<b>Human (Tim):</b>	The books may get wet.
<b>Lisa:</b>	Why do you still have your water bottle, Ron? Look at rule number 2. We cannot get in the library with food or drink.

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# **AutoTutor Trialogues to Help Struggling Adult Readers**



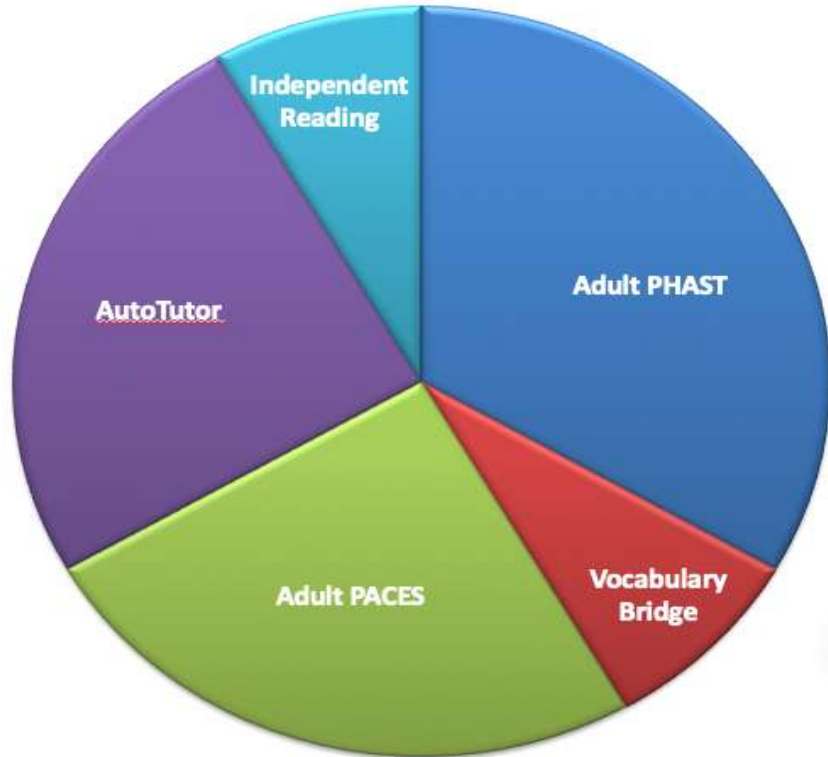
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# Intervention to Improve Reading for Adults



- Adults who read at grade levels 3-7.9
- 100 instructional hours
- 2 times weekly
- 2-3 hours per duration
- Atlanta and Toronto areas
- 253 in the intervention
- Comparison to business as usual

# Adult PACES Comprehension Program

- **P = Predicting purpose with text signals and key information.**
- **A = Acquiring vocabulary with context clues.**
- **C = Clarifying common sources of confusion with clarifying questions.**
- **E = Evaluating and elaborating through questioning.**
- **S = Summarizing with text maps.**

Lovett, M.W., Lacerenza, L., De Palma, M., & Frijters, J.C. (2012). Evaluating the efficacy of remediation for struggling readers in high school. *Journal of Learning Disabilities*. 45, 151-169.

# Multilevel theoretical framework of discourse comprehension

**Words**

**Syntax**

**Textbase**

Explicit ideas (propositions)

Referential cohesion

**Situation model**

Causal, intentional, temporal,  
spatial, logical relationships

Connectives, signaling words

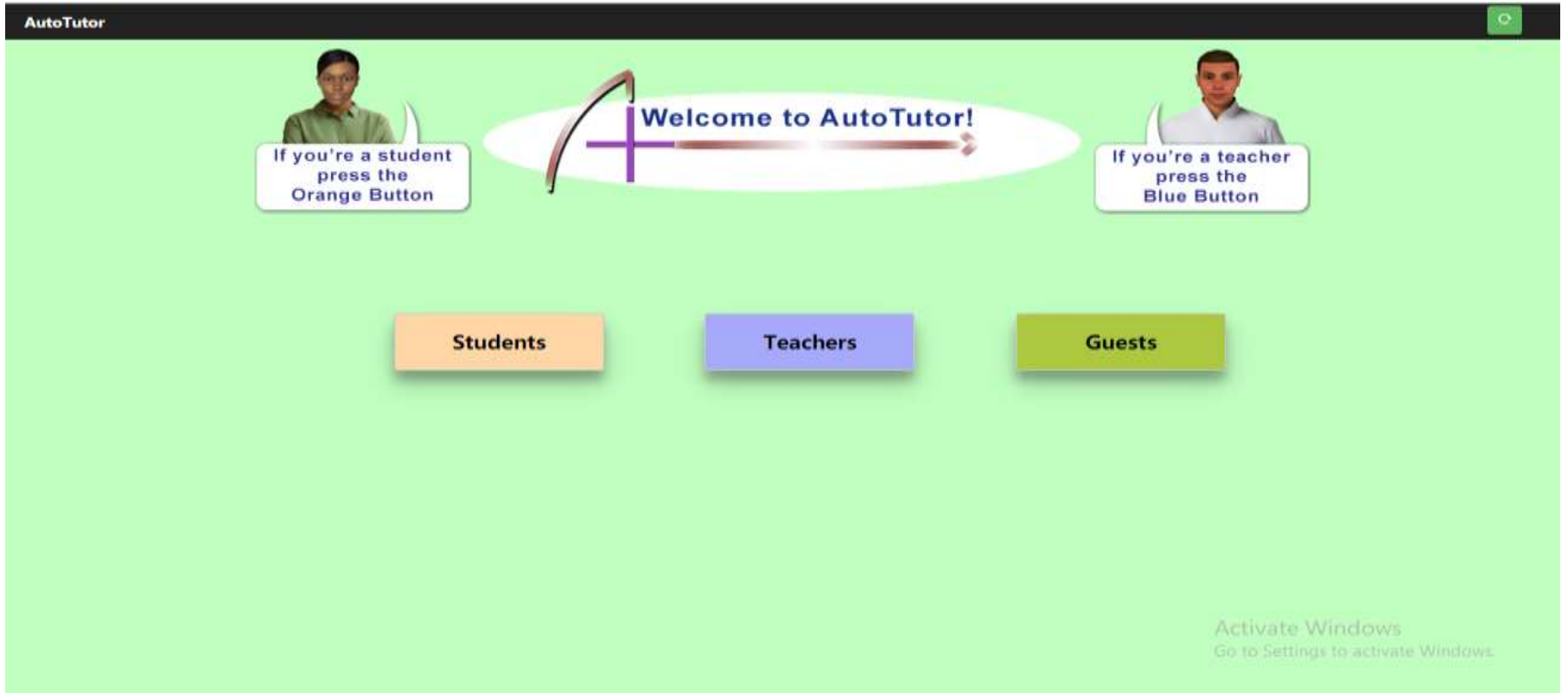
**Genre and rhetorical structure**

**Pragmatic communication**

Graesser, A.C., & McNamara, D.S. (2011). Computational analyses of multilevel discourse comprehension. *Topics in Cognitive Science*, 3, 371-398.

Also Goldman, Kintsch, Perfetti...

# Home Web Page



The screenshot shows the AutoTutor home page with a light green background. At the top left, the text "AutoTutor" is displayed in a black header bar. In the center, a white oval contains the text "Welcome to AutoTutor!" with a purple crosshair and a red arrow pointing right. To the left of the oval is a speech bubble with a man's image and the text "If you're a student press the Orange Button". To the right is another speech bubble with a man's image and the text "If you're a teacher press the Blue Button". Below these are three buttons: an orange "Students" button, a blue "Teachers" button, and a green "Guests" button. In the bottom right corner, there is a watermark for "Activate Windows" with the instruction "Go to Settings to activate Windows."

AutoTutor

Welcome to AutoTutor!

If you're a student  
press the  
Orange Button

If you're a teacher  
press the  
Blue Button

Students

Teachers

Guests

Activate Windows  
Go to Settings to activate Windows.

# Scope of Lessons



To begin, look at all the skills we have to teach you.



Then, just press on the lesson you want to learn!

## Words and Sentences

First Lesson	Punctuation
Word Parts	Non-Literal Language
Word Meaning Clues	Text Signals
Learning New Words	Purpose of Texts
Multiple Meaning Words	Review 1
Pronouns	

## Computer and Internet

Forms and Documents
Searching the Web
Social Media
Using Email
Job Applications

## Stories and Text

Main Ideas	Problems and Solutions
Connecting Ideas	Compare and Contrast
A Personal Story	Cause and Effect
Complex Stories	Describing Things
Persuasive Texts	Time and Order
Complex Persuasive Texts	Inferences from Texts
Steps in Procedures	Review 2

# Database for Instructor

AutoTutor Welcome Anne Log Out

Classes Management | My Desktop | Report | My Classes

Lesson Breakdown

**Lessons** **Adults** **Performance**

Lesson	Class Avg	hsc010301550	hsc010301552	hsc010301553	hsc010301554	hsc010301556	hsc010301557	hsc010301561	hsc010301562	hsc010301564
0. Introduction										
1. Text Signals	84%	76% ✓		87% ✓	87% ✓		80% ✓			
2. Writer's Purpose	62%			0%	70%		100%			
3. Hybrid Texts	77%			79% ✓	75% ✓	67% ✓				
4. Affixes	74%	81% ✓		70% ✓			78% ✓	74% ✓	70% ✓	75%
5. Punctuation	61%	64% ✓	36%	64% ✓	72% ✓	32% ✓	82% ✓	61% ✓	82%	100%
6. Context Clues	75%	72% ✓	64% ✓	91%	80% ✓		79% ✓	82%	91% ✓	75%
7. Acquiring New Words	95%	90% ✓					100% ✓			
8. Multiple Meaning Words			67% ✓		80% ✓		89% ✓	90% ✓	78% ✓	70% ✓
9. Pronouns	85%			69%	96% ✓		91% ✓	87% ✓	70% ✓	91% ✓
10. Non-Literal Language	82%	82% ✓			87% ✓		77% ✓	92% ✓	90% ✓	
11. Review	82%				100% ✓		71% ✓	86% ✓	71% ✓	
12. Using Key Information	100%	100%								
13. Questioning: Narrative	68%			60%	100% ✓	60% ✓	80% ✓		80% ✓	
14. Bridge Building										
15. Summarizing Narrative	63%		56% ✓	70%	82% ✓		82% ✓		74%	
16. Questioning: Informational	70%		80% ✓		75% ✓		80% ✓	73% ✓	65% ✓	
17. Questioning: Persuasive	57%			91% ✓	52% ✓		58% ✓		41% ✓	
18. Review	59%		44% ✓	76% ✓	81% ✓	0%	100% ✓		32% ✓	
19. Statement and Explanation										
20. Problem Solution	73%		65% ✓		75% ✓		75% ✓	75% ✓	78%	
21. Cause and Effect	71%		59% ✓	59% ✓	72% ✓		76% ✓	81% ✓	82%	82%

Activate Windows  
Go to Settings to activate Windows.



# More Details about AutoTutor for CSAL

- **35 lessons on comprehension**

20-60 minutes each

Summary Nugget → Conversational Training

Cover theoretical components and PACES curriculum

- **Conversation patterns**

Agents in dialogues generate questions, hints, feedback, corrections, explanations, and guidance on using the system

Conversation modes: Testing, helping the peer, game competition

Minimal natural language input from adult

- **Multiple media**

- **Practical texts and tasks for adults**

# AutoTutor Trialogue



Teacher Agent:  
Cristina



Peer Agent:  
Jordan

## To Raise the Minimum Wage in America

*Economics paper written by Andrew Pink for Intro to Economics at the University of Antarctica*

Do you think living on \$7.25 per hour is enough to survive in America? Do you think there should be a wage increase, say, to \$9 per hour? Well I think there should be an increase in the level of minimum wage. I think it's important to allow people to earn more money, that way they can live comfortably- live above the poverty line. Also, I read in Forbes that people who are currently under paid would keep their jobs if they receive an increase, and this will be

What is the topic of the article?

Poverty

Government issues

Minimum wage

Repeat



Participants read text and answer question

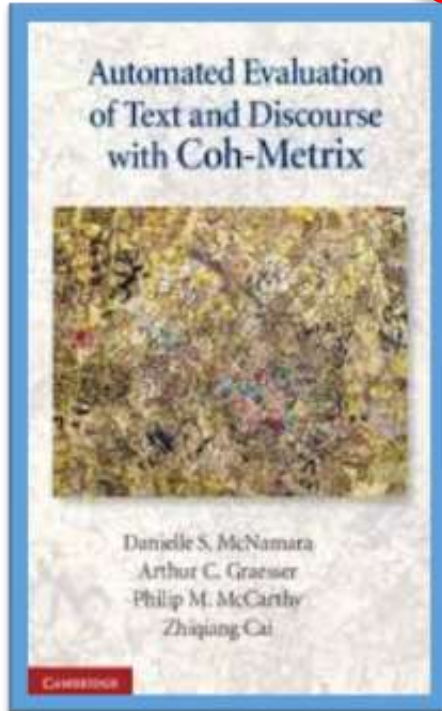
# Tutorial On Digital Literacy



# Discourse Formality

Informational Genre + High Cohesion +  
Complex Syntax + Abstract Words

Cohmetrix.com  
Zhiqiang Cai



**Coh-Metrix**  
Text Easeability Assessor

Home Common Core Standards Tools Research FAQ Comment Contact Us Hello Jeremiah !!

Enter text here:

Thousands of years ago, our ancestors invented the map. Ancient maps were crude but very useful tools. They helped people find food, clean water, and the way back home—even when home was a cave. As civilizations grew, better maps were needed. The oldest existing maps are from the ancient kingdom of Babylonia. These maps were etched on tablets of damp clay that soon baked rock hard in the midday sun. Early Chinese mapmakers painted beautiful maps of their empire on pure silk cloth. People in every part of the world cleverly used local materials to make maps they wanted and needed. Charts are maps used to sail the wide oceans. The Polynesian Islanders sailed the vast Pacific Ocean using slick chart maps. These charts were woven with

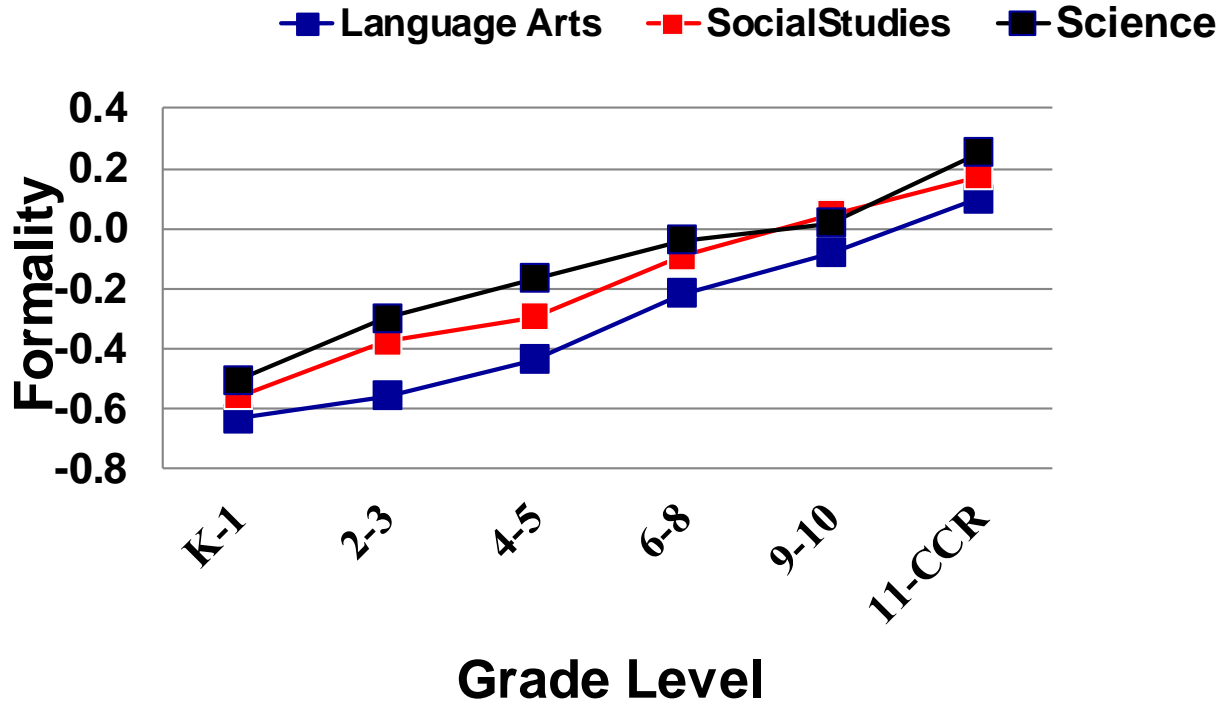
Pro-process Analyze Clear

Metric	Percentage
Narrativity	17%
Syntactic Simplicity	71%
Word Concreteness	88%
Referential Cohesion	42%
Deep Cohesion	24%

Flesch Kincaid Grade Level 9.6 (6-7)

This text is low in narrativity which indicates that it is less story-like and may have less familiar words. Less story-like texts are usually harder to comprehend. It is high in syntactic simplicity which means that it has simple sentence structures. Simple syntax is easier to process. This text has high word concreteness, which means there are many words that are easier to visualize and comprehend. It is low in both referential and deep cohesion, suggesting that the reader may have to infer the relationships between sentences and ideas. If the reader has insufficient prior knowledge, these gaps can be challenging.

# Coh-Metrix Formality Scores as a Function of Genres and Grade Levels

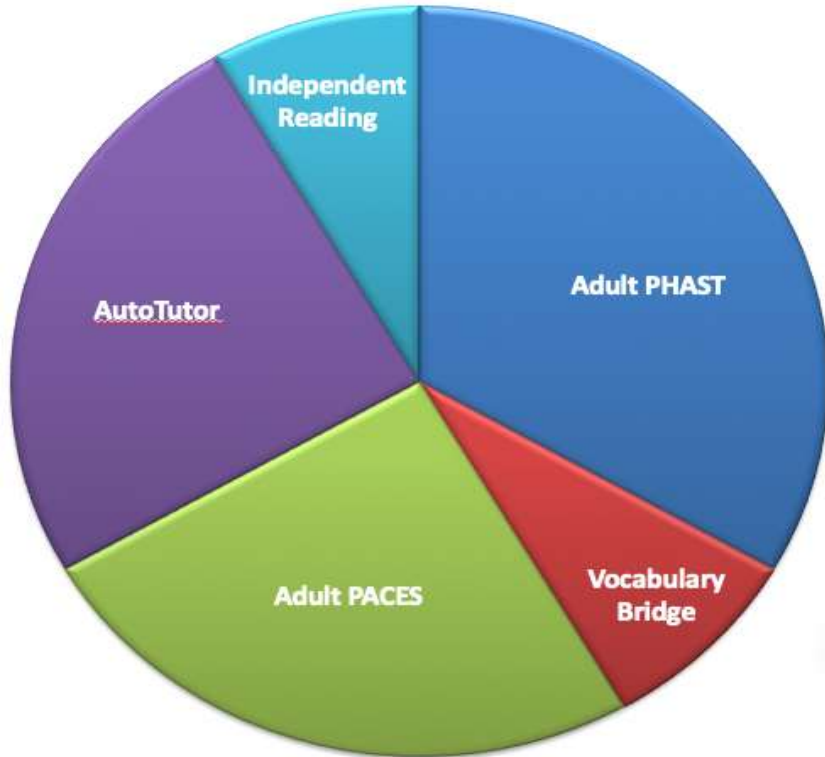


Graesser, A.C., McNamara, D.S., Cai, Z., Conley, M., Li, H., & Pennebaker, J. (2014). Coh-Metrix measures text characteristics at multiple levels of language and discourse. *Elementary School Journal*. 115, 210-229.

# Types of Adaptivity

- **Lessons start out at a medium level of difficulty and branch to easy or hard depending on performance.**
- **In the inner loop (VanLehn, 2006), the conversational moves depend on the input of the adult learner.**
- **In the game competitions, the peer agent's actions always end up losing to the adult learner at the end.**

# Intervention Design



- I. Pretest on dozens of measures
- II. Intervention (100 hours)
- III. Posttest with dozens of measures

## Three comprehension measures

- Woodcock-Johnson
- Sara (Educational Testing Service)
- Lexia (formerly Rapid)

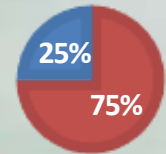
# Study on Adult Readers (N=253)

4 month  
intervention  
on 26 lessons

- Age: 16-69
- Reading Grade Level: 3.0 – 7.9

## GENDER

Female Male



Toronto  
★ *n* = 118



Atlanta  
★ *n* = 135



# Overall Results of AutoTutor

- **Completion of lessons**

- 26 lessons were used in the analysis
- 68.2% of lessons attempted
- 55.3% of the lessons completed

- **Performance in answering questions**

- 68% answered correctly on first attempt
- 78% likelihood of branching to difficult texts rather than easy texts/items after performing on medium texts/items
- 32.8 seconds per question

# Cluster Analysis

## Features

- Performance time & accuracy crossed with four levels of reading comprehension  
(Words, Textbase, Situation model, Rhetorical structure)

## Method

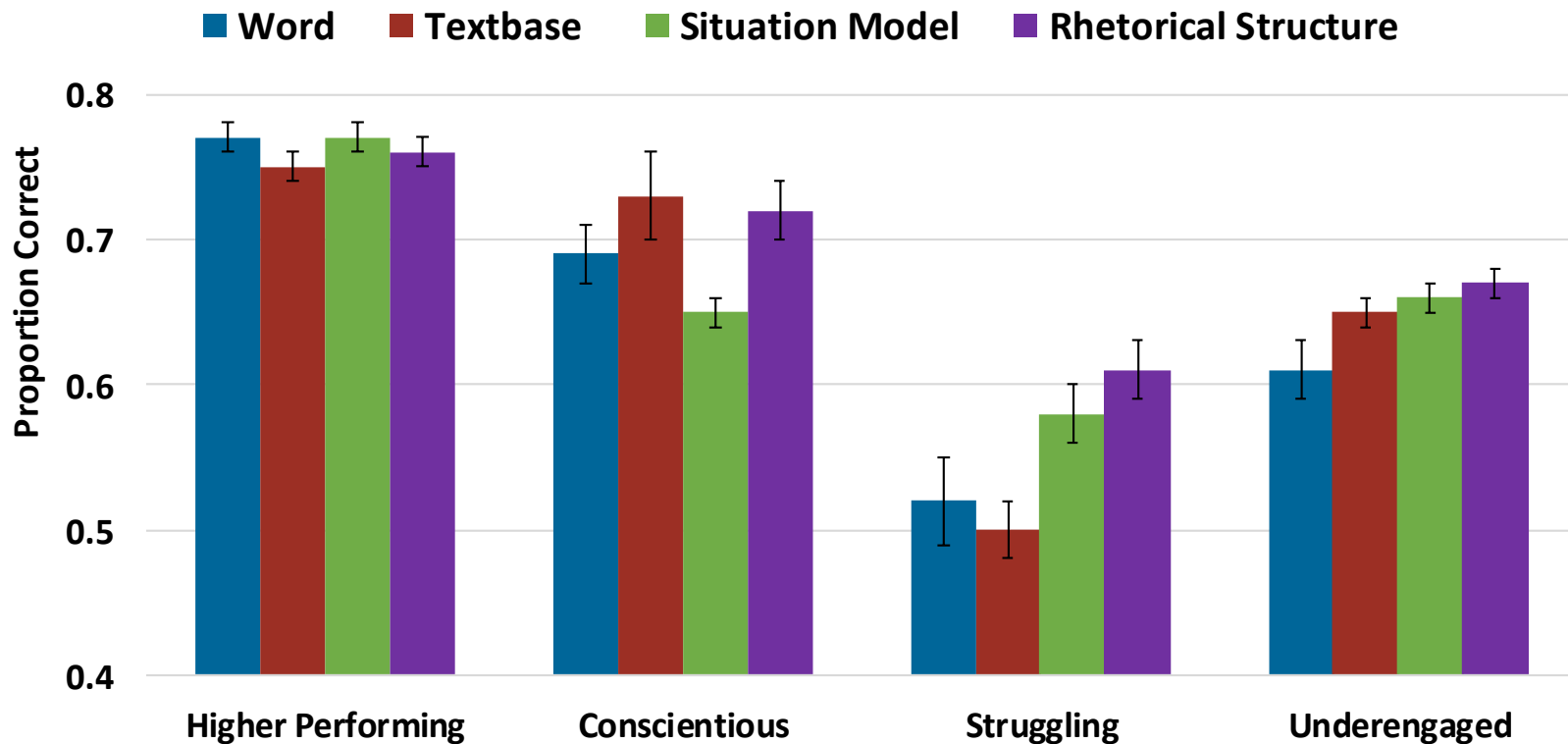
- K-means clustering VS hierarchical agglomerative clustering  
(Connectivity, Silhouette Width, Dunn Index)
- Hierarchical clustering performed better

**Fang, Y.**, Shubeck, K.T., Lippert, A., Cheng, Q., Shi, G., Feng, S., Gatewood, J., Chen, S., Cai, Z., Pavlik, P. I., Frijters, J.C., Greenberg, D., Graesser, A. C. (2018). Clustering the Learning Patterns of Adults with Low Literacy Interacting with an Intelligent Tutoring System. In K.E. Boyer & M. Yudelson (Eds.), *Proceedings of the 11th International Conference on Educational Data Mining* (pp.348-354). Buffalo, NY: Educational Data Mining Society.

# Four Clusters of Readers based on AutoTutor Response Times and Accuracy

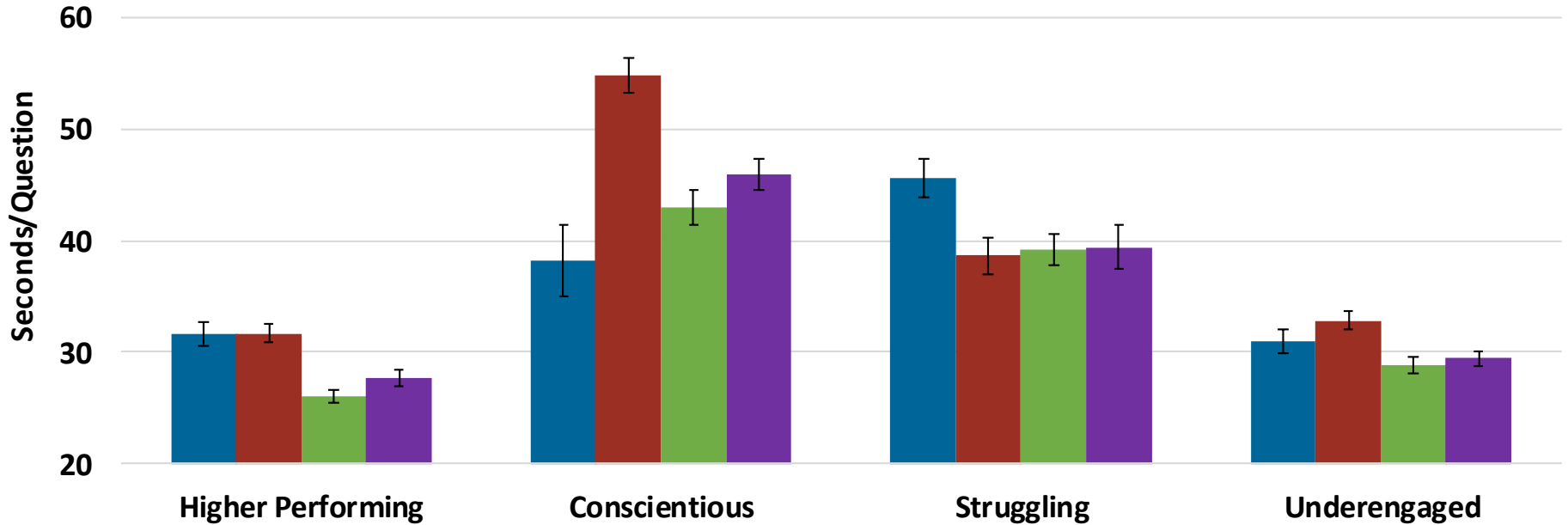
1. **Struggling** readers showed minimal gains and may be wheel spinning. Slow plus inaccurate.
2. **Under-engaged** readers don't spend quite enough time that they need. Fast and lower accuracy.
3. **Conscientious** readers are slow and higher accuracy.
4. **Higher performing** readers are relatively fast and accurate.

# Accuracy as a Function of Theoretical Level and Reader Cluster

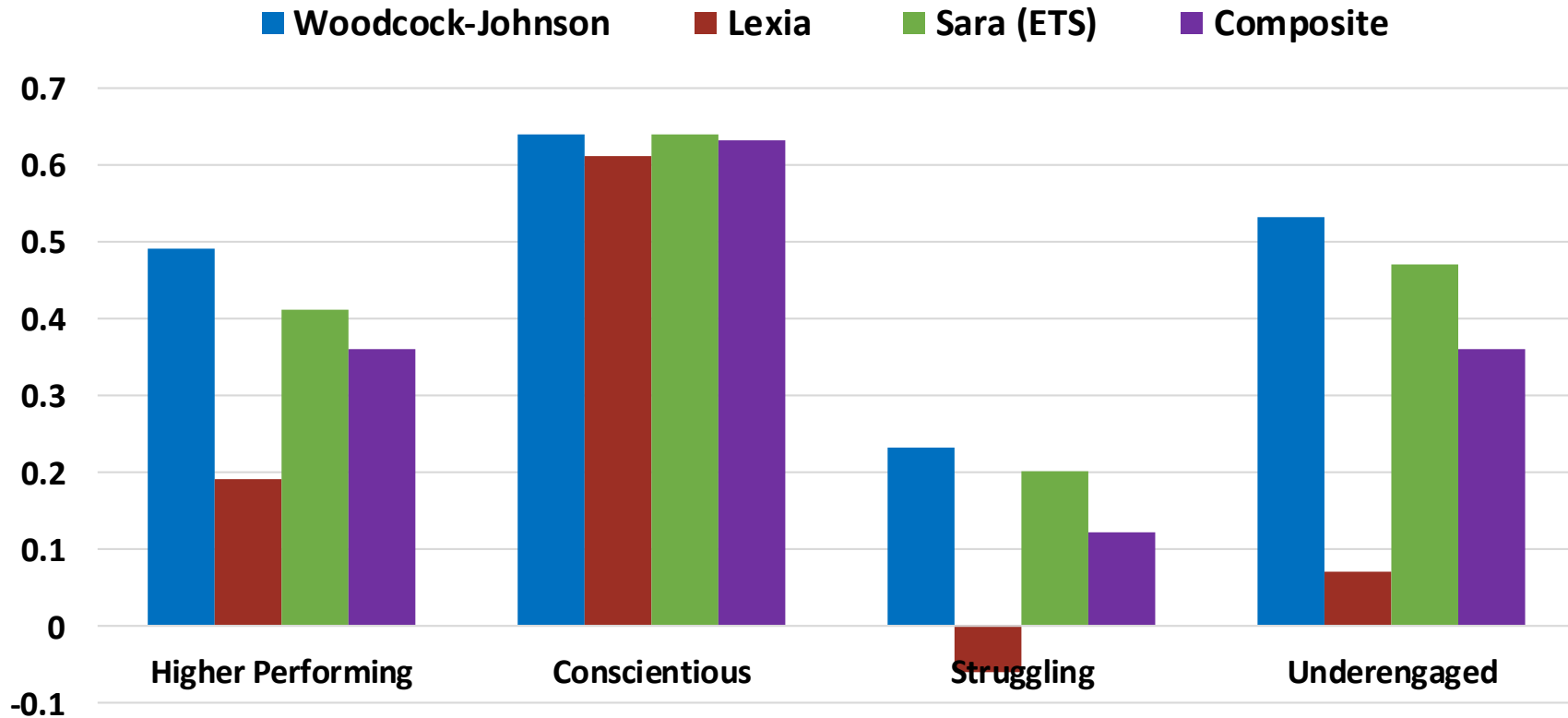


# Time per Question (seconds) as a Function of Theoretical Level and Reader Cluster

■ Word   ■ Textbase   ■ Situation Model   ■ Rhetorical Structure



# Effect Sizes (posttest minus pretest) on Learning Gains as a Function of Reader Cluster



# The four clusters of readers show very different profiles

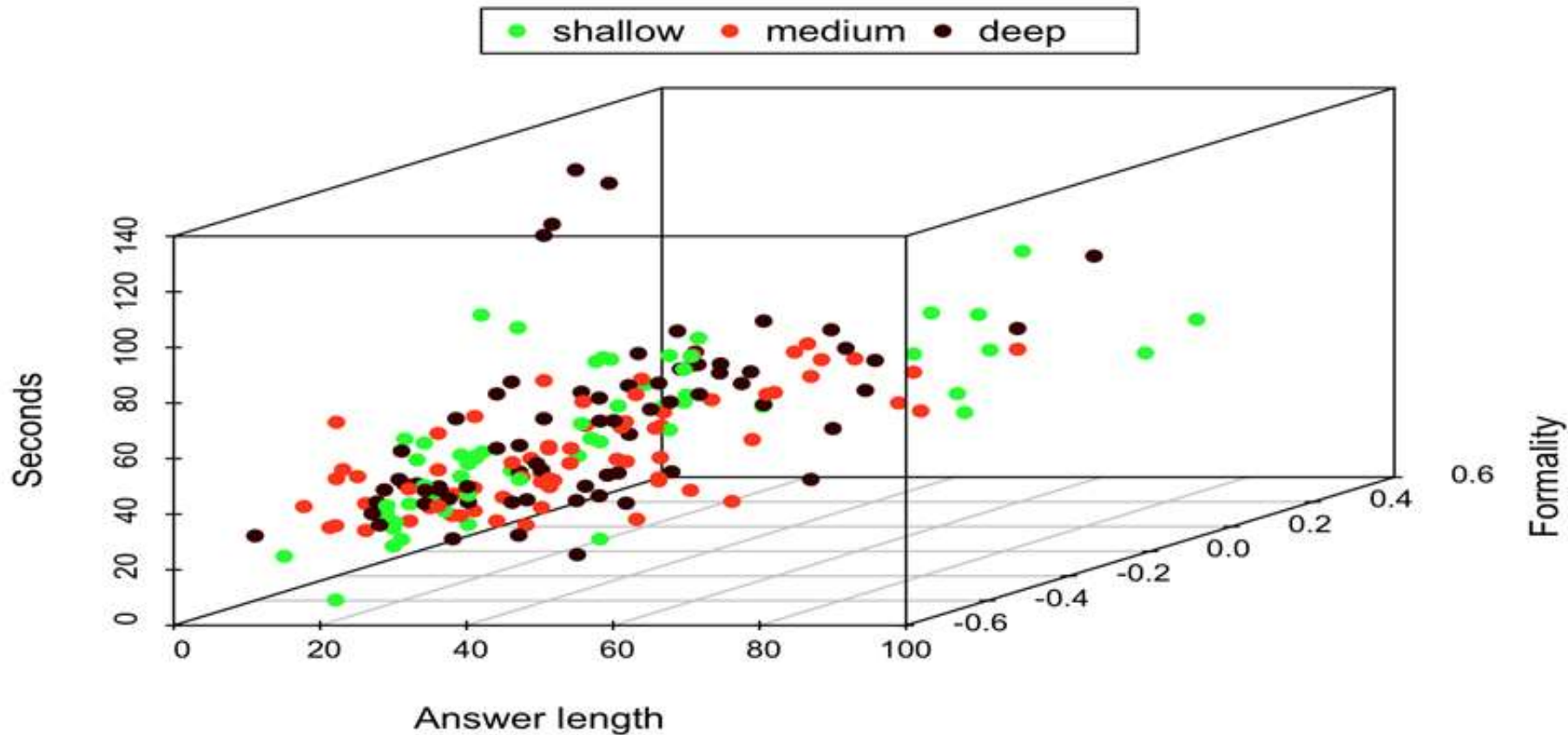
1. **Struggling** readers showed minimal gains and may be wheel spinning. The intervention is beyond their zone of proximal development.
2. **Under-engaged** readers need to be encouraged to spend more time concentrating or otherwise be motivated more.
3. **Conscientious** readers are the major beneficiaries.
4. **Higher performing** readers may benefit from more challenge and be encouraged to increase reading activities.

# Item Analyses: Mixed-effects Models (Ying Fang)

- **Predictor variables**
  - Text formality score
  - Question depth level (Bloom's taxonomy)
  - Answer length (log of number of words in options)
- **Dependent variables**
  - Time on question in seconds
  - Correctness of answer to question
- **Random effects**
  - Participants
  - Texts



# Predicting time in 1st attempts

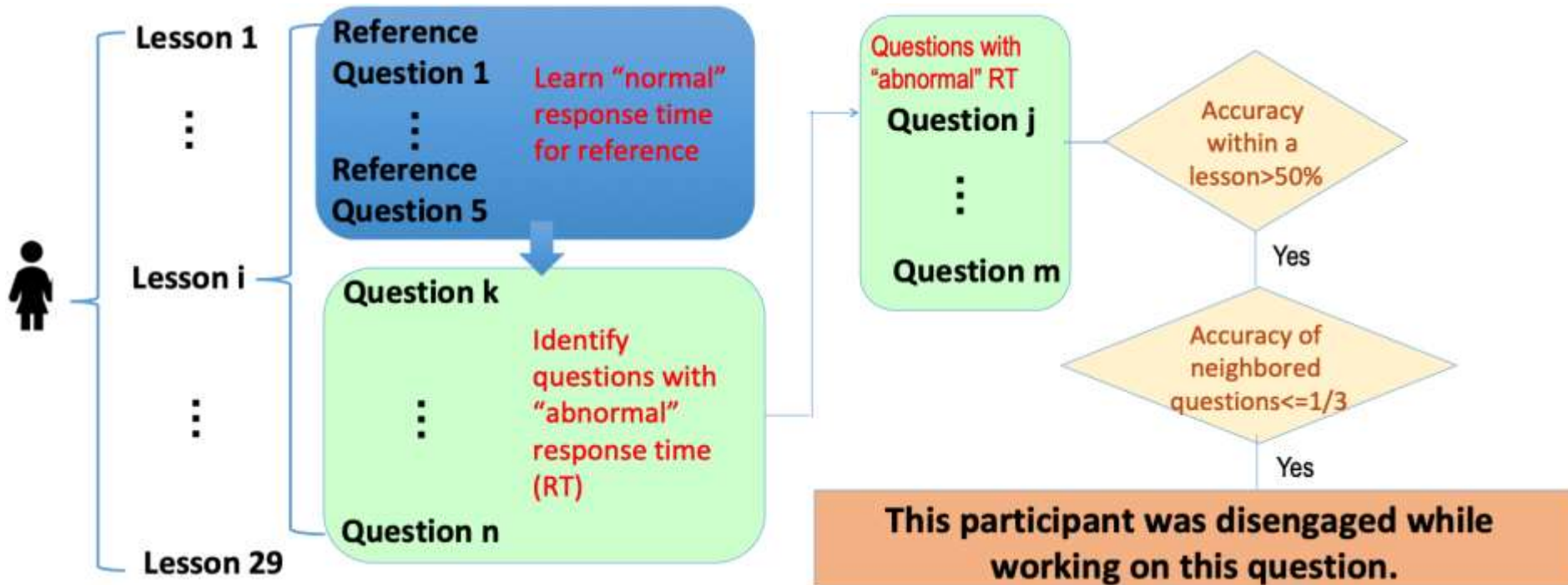


# Results on Time and Accuracy of Question Items

	Text Formality	Question Depth	Answer Length
First Attempt Time	+	+	+
Subsequent Attempt Time		+	+
First Attempt Accuracy	-		-
Subsequent Attempt Accuracy		-	-

# Disengagement Tracing System (Su Chen)

## Algorithm Flow Chart



# Upshot of Question Item Analyses

- Identify disengagement time spans of individual readers
- Quickly classify individual readers into one of the four reader clusters (**struggling, under-engaged, conscientious, higher performers**)
- Design AutoTutor to select materials and dialogue moves that are sensitive to these characteristics

# Immediate Next Steps

- **AutoTutor in the Wild**
- **Explore how much human instructor scaffolding is needed?**
- **Scaling up AutoTutor for:**
  - adult literacy centers**
  - workforce**
  - colleges, universities, Department of Defense training**

# Long-term Horizon with AI

- **Build a more adaptive AutoTutor**
  - Sensitivity to engagement and reading clusters
  - Sensitivity to interests of the reader (Andrew Olney)
- **Speech recognition and mobile devices**
- **Social connections through social media:**
  - Human connections with peers and instructors
  - Will they believe intelligent bots?
- **Integration with Geographical Information Systems**
  - You are near a literacy center, bookstore, library...
  - You like Chinese food. What do you think about this restaurant?

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**Institute for Intelligent Systems**  
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**Thank you!**

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