



## Learning Analytics: Modeling, Understanding, and Changing Student Behavior

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### Innovations in Learning: **The Second Second**







UNC CHARLOTTE B.S. Computer Science B.A. International Studies

Minor: Japanese





1.5 Years Abroad



Data Science Internships



PhD Computer Science

Computational and Data Sciences



**Assistant Professor** 









Output











#### **Modeling Behavior**







#### **Understanding Behavior**







#### **Changing Behavior**















**Data Science Back Ground** 

#### Player Centered Data Science Learner Centered Data Science

PhD













#### **Data Science**







#### Data Science: Where are you?







#### Why Human Centered Data Science?

- Intersection of multiple fields
- Research Methods
- Rapid Feedback Loops
- Understanding and modeling users
- Changing behaviors
- Communication with Design Teams
- Scrappy Science





#### **Data Science: Hat Balancing**

- Balance Between
  - Qualitative
  - Quantitative
  - Machine Learning
  - Rigor vs. Speed
  - Communication





Innovations in Learning: **The Provide Active State** From Possibilities to Practice



#### **Research Methods in Data Science**

- Most people agree that Statistics and Machine Learning are core components of Data Science
- Less agreement on *Inferential* Statistics and Social Research Methods
- Experimental Testing Expertise is Increasing Desired from Industry (A/B Testing, etc.)





#### **Qualitative Data?**

- Connected to domain knowledge
- Understanding new environments
- Guard against missing variables
- Understanding the products
- Get Insight Before Launch











## **Learning Analytics**

Where we are going





Tools that empower the designer, instructor, and students

- Predictive models that identify dropout
- Decision support for instructors
- Adaptive and personalized education
- Large systems that pull together lots of data

### **SCALE:** STUDENT-CENTERED ADAPTIVE LEARNING ENGINE



#### **SCALE Onboarding Process**

#### ASSESS

TutorGen leads a review of existing client content and data to develop insights. Our process uses existing data with our architecture to reduce cost by not having clients recreate what they already have built.



#### ANALYZE

TutorGen analyzes current data to identify opportunities and gaps within existing content to create an approach tailored to the needs of our clients and their learners.



#### Adapt

Using a continuous data-driven process, SCALE creates and updates problem and student models, building from subject matter experts, to personalize delivery of existing content to improve learning.



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•	Larry Rice	Pre-test		7/29/2018	Pre-test	70.22%		Pre-test	Student is confident.	
•	Paul Aronson	Final Assmt.	- <b>1</b>	7/20/2018	Additional Preparation	65.43%		Pre-test	Student needs more practice.	
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8	Robert Burke	Add'l Prep.		//4/2018	Additional Preparation	60.73%		Additional Preparation	student needs more practice.	

#### **CheckPoint Features**

#### **Process**

Supporting a wide variety of data streams to extract features used to build real-time, predictive student models.

#### **Predict**

CheckPoint performs continuous evaluation of available data streams and provides a prediction of student success and specific assessment performance.

#### Prompt

The CheckPoint dashboard interface recommends student interventions, tracks actual activities, and evaluates student results for review and tuning.



:45PM





Tools that empower the designer, instructor, and students

- Predictive models that identify dropout
- Decision support for instructors
- Adaptive and personalized education
- Large systems that pull together lots of data
- Where do we start?





## Background

How a few questions started a massive journey...





#### **First Research: Educational Games**



#### Developed games to teach computer science

### Learned about games in education

or(i=0:i<=3:i = i + 1)

S\_array[i][j] = SnowArms; S\_array[i][j] = SnowHat; S\_array[i][j] = Destroy;

for(j=0;j<=9;j = j + 1)





#### Wu's Castle: Array







#### **Stratified Sample**



### Pretest scores



Innovations in Learning:



#### **Switching Replications**

Strong experimental design

Does not deny the game to some students

Provides solution for social confounds

• No one gets jealous of game-playing group

Provides insight into ordering effects





#### **Study Design**

#### **Experimental Group**









## 

#### Short-term persistent treatment effect





## A CONTRACTOR

#### Long-term continuing treatment effect





Innovations in Learning:



#### **Study Design**

#### **Experimental Group**







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#### Long-term continuing treatment effect







#### Conclusions

- Game resulted in improved learning
  - Learning gains continued after game was played
- Both assignments combined provide better results
  - Game-first ordering is preferred





# **Personal Motivation** Posttest Pretest The Interesting Stuff is Happening During the Treatment





#### Other methods of evaluation

- Techniques from:
  - Intelligent Tutoring Systems (ITS)
    - Systems that provide direct customized instruction or feedback to students without human intervention
  - Educational Data Mining (EDM)
    - Methods for exploring the data that comes from educational settings





ACT-R (1983)







#### **Declarative Module**

- Declarative memory:
  - Facts
    - Washington, D.C. is the capital of the U.S.
    - 2+3=5.
  - Knowledge a person might be expected to have to solve a problem.
  - Called chunks




#### **Procedural Module**

- Procedural memory: Knowledge about how to do something.
  - How to type the letter "Q".
  - How to drive.
  - How to perform addition.



#### **Procedural Module**

- Made of condition-action data structures called production rules.
- Each production rule takes 50ms to fire.
- Serial bottleneck in this parallel system.













#### **Procedural Module**

(р example-counting =goal> isa count state counting number =num1 =retrieval> isa count-order first =num1 second =num2 ==> =goal> number =num2 +retrieval> isa count-order first =num2

#### IF the goal is to count the current state is counting there is a number called =num1 and a chunk has been retrieved of type count-order where the first number is =num1 and it is followed by =num2 THEN change the goal to continue counting from =num2 and request a retrieval of a count-order fact for the number that follows =num2











#### **Empirical Learning Curves (ELC)**

- Visualization of a student's performance over time, based on observed data.
- Learning curves:
  - Observations of skill improvement with practice follow power law (Newell 1993)





#### **Learning Curves**

- *E* = *Xn^a* 
  - *E* performance criteria
  - *X* performance of first trial
  - *n* describes the opportunity to practice a skill
  - *a* describes the learning rate





#### Learning Curve Example







#### Learning Curve Example







#### Learning Curve Example





## Innovations in Learning: From Possibilities to Practice



#### Flow





Innovations in Learning: 
From Possibilities to Practice







Innovations in Learning:



-			













#### **Ideal Learning Curve**







#### **Ideal Learning Curve**





Innovations in Learning: **The Possibilities to Practice** 

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#### Long-term continuing treatment effect





Innovations in Learning: 
From Possibilities to Practice







Innovations in Learning: 
From Possibilities to Practice







Innovations in Learning: **The Possibilities to Practice** 









#### Learning Curve Conclusions

Learning curves can provide insight into learning from within a game

Analysis of learning curve data could improve game challenge balancing

Learning curves provide a non-invasive way to demonstrate learning effects

Study of learning curves in games can help define a research paradigm for games





#### **Cognitive Genetics Tutor**







#### **New Predictive Features**





Innovations in Learning: **The Possibilities to Practice** 



#### Individualized Learning Curve





KC1 3

4

KC1



#### Learning Curves: Visualization of Learning as it Happens

Student ID	Knowledge Component	Opportunity	Corre	ct		
S1	KC1	1	0			
S1	KC1	2	1			
S2	KC1	1	1 0			
S2	KC2	1	1 1			
S3	KC3	1	0			
				КС	Opportunit	
				KC1	1	
				KC1	2	

Mission-focused, Employee-centric, Teamwork, Integrity, Speed

Probability

0.7

0.5

0.25

0.15



KC1 3

KC1 4



#### Learning Curves: Visualization of Learning as it Happens

Student ID	Knowledge Component	Opportunity	Correc	t	
S1	KC1	1	0		
S1	KC1	2	1		
S2	KC1	1	0		
S2	KC2	1	1		
S3	KC3	1	0		
				КС	Opportunity
				KC1	1
				KC1	2

### Can be done in Excel

Mission-focused, Employee-centric, Teamwork, Integrity, Speed

Probability

0.7

0.5

0.25

0.15





### Less constrained environments?

 Cognitive Modeling with BKT works well when the knowledge components are well defined

Student	Knowledge	Opportunity	Correct			
ID	Component					
S1	KC1	1	0			
S1	KC1	2	1			
S2	KC1	1	0			
S2	KC2	1	1			
S3	КСЗ	1	0			

• What about when they are less clear?











#### **Expected Pass Behaviors**





Innovations in Learning: **The Possibilities to Practice** 





### Visualization





Innovations in Learning: **The Possibilities to Practice** 









# What behaviors describe non-passing students? Visualization

Reason	Proportion			
Quit Early, low use of resources	13%			
Has Activity, Complete Testing Avoidance	4%			
Has Activity, Predicted Pass w/o Test	35%			
Ran out of time in term (Started very late)	8%			
Low Activity	22%			
Not Explained	18%			





Innovations in Learning: **The Second Second** 



## **Interaction Networks**

A Data-Driven Method for Understanding, Evaluating, and Changing Behavior in Educational Problem Solving



Innovations in Learning:



# My High Level Work Flow

**Short Version** 





#### **Example Interactions**

- Interaction 1: User moves from Step 0 to Step 1 via the SIMP rule
- Interaction 2: User moves from Step 1 to Step 2 via the B-ADD rule





## Innovations in Learning: From Possibilities to Practice



#### **Interaction Logs**

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### **Performance Analysis**







### **Transactional Analysis**







### **Interaction Network**







### **Edge-Betweenness Regions**







### **Reduction to Regions**







### **Different Layout**







### **Approach Maps**







### **Open-ended Environments**

- Body of my dissertation research
- Focus is not on KCs
- Use State-to-State data to produce ITS like feedback







# **Alice Environment**

Play Undo Redo	🛅	
world PR camera Q3 light ground candyCane1 C girl	Events create new event When the world starts, do world.checkCandy - When the world starts, do girl.tumLeft - When the is typed, do girl.tumRight -	
world's details properties methods function checkCandy edit create new method	<ul> <li>id.checkCandy No parameters</li> <li>rariables</li> <li>// this is a method that moves the woman forward until she touches the candy cane -</li> <li>While not girl.body.rightArm.forearm.hand - is within 1 meter - of candyCane1</li> <li>Do in order</li> <li>girl - move forward - 1/10 meters - style = abruptly - duration = 0.5 seconds - more</li> <li>Do together</li> <li>girl.body - move forward - 0.1 meters - more</li> <li>girl.body - turn forward - 1.5 revolutions - more</li> <li>girl.body - turn forward - 1.5 revolutions - more</li> <li>girl.body - turn forward - 1.5 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> <li>girl.body.rightArm - turn left - 0.25 revolutions - more</li> </ul>	Code





### Data-Driven Learning Analytics for Assessing Computational Thinking

- Collaboration with SRI
- Attempting to derive meaningful CT concepts from low-level data







# **Alice Environment**

Play Undo Redo		
world Camera Cight cond cond candyCanel CondyCanel CondyCanel	Events create new event When the world starts, do world.checkCandy - When - is typed, do girl.turnLeft - When - is typed, do girl.turnRight -	
world's details properties methods function checkCandy edit create new method	<pre>w fid.checkCandy No parameters N cariables // this is a method that moves the woman forward until she touches the candy cane -</pre>	Code





### **Track the Code-State After Each Student-Alice Interaction**







### **Track the Code-State After Each Student-Alice Interaction**







### Each Code-State is Represented as a Vertex in the Network







### Data from Fairy Assessment Task (From ETR)

### For ~315 students

- Final .a2w files and corresponding .txt log files
- Manually graded projects per rubrics

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### **Results**

- Can predict the overall success of students based on their solution paths
- We can identify important code-chunks that math the human defined rubric



### Is this result useful?

- Simulated classroom dashboard to explore how useful the information would be
- Subsampling and time alignment to simulate a lab session





## Classroom Replay in an Instructor Dashboard





### Matching students with peer tutors can increase the amount of help







# **Questions?**





### **Deep Thought Logic Tutor**

- The goal is defined, but the process to the goal is not
- There are a finite number of actions used to manipulate the environment
- Success is determined by relevant or useful application of rules





## Innovations in Learning:



### **Hint Effects**





### **Hint Factory Primary Results**

- Control group odds of dropping after first six problems was 3.6 times that of the experimental group
- Hint group out performed the control group by about half of a standard deviation in terms of tutor performance
- Hint group had a higher overall course score by one third of a standard deviation when compared to the control group



### **Reason for Dropout Differences?**

- In what way did the Hints prevent student dropout?
- Did Lack of Hints resulted in Control Students becoming frustrated and quitting.
- Did students in each group spend different amounts of time in tutor?
  - Turns out to be a complicated question.





### **Questions to Answer**

- "How long would it take students to complete the tutor"
  - Vs. "How long did it take to complete the tutor (for those that managed.)"
- "Were there time differences between-groups?"
  - Vs. "Were there time differences between-groups (for students that managed to finish the tutor"





### **Tutor Efficiency**

- "How long does it take students to complete the tutor."
- Three Elements
  - Performance tutor completion percentage
  - Duration total time spent interacting with the tutor
  - Dropout whether stopped before completion





### **Dropout Bias**

- Different dropout/attrition rates between experimental groups causes attrition bias
  - The students are self-selected due to achievement levels
- Is a threat to the study generalizability





### **Duration data is not Normally Distributed**







### **Survival Analysis**

- Survival Function
  - S(t) = Pr(E > t) = 1 F(t)
  - t the time in question
  - E the time of the Event (tutor completion)
  - F(t) the duration distribution
- Gives the probability that the time of the tutor completion event, E, is later than t.
  - "The probability that the student has not completed the tutor."





### **Right Censoring**

• We know the *tutor-start time* but do not always know the *tutor-complete time* 







### **Accelerated Failure Time (AFT)**

- Assumes that the effect results in one group having a shortened or lengthened lifetime
- $S(t | \theta) = S(\theta t)$ 
  - $\Theta$  is a direct modifier to the tutor completion time





### **Results**

- Intercept (mean) = 5.655
- Θ = -0.599
  - Hint group takes 55% of the time it takes the control group to complete the tutor
- Control Median
  - E<sup>5.65</sup> = 284.29
- Hint Median
  - $E^{5.65-.599} = 156.18$





### **Survival Curve**





### **Estimate Time Needed**

- "How much time is needed so that 50% of the students can complete the tutor."
- Using the Survival function S(t) = .5, we can estimate that:
  - Control group needs 4.76 hours
  - Hint group needs just 2.61 hours





### **New Understanding**

- We know about the observed performance differences
- We understand dropout's connection to learning efficiency
- But, where is the control group's time going?




# **Other Domains?**

Interaction networks have worked in a number of environments



Z&~W

 $Z \rightarrow (\sim Y \rightarrow X)$ 

 $W \vee (T \rightarrow S)$ 

~YvT



#### **Propositional Logic Tutor**







#### Cartesian coordinate puzzle game





## Innovations in Learning: **The Provide Active State** From Possibilities to Practice



#### **Programming Game**







#### **Optics Game**







#### **Interaction Network as a Construct**



- Internal (unobservable) cognitive processes happen between steps
- Application of rules results in changes in the external environment (observable)
- If rule selection is governed by cognitive biases, then the observable output will reflect this
- That is:
  - A random walker will perform different than a bias walker
  - Walkers with different biases will perform differently



Innovations in Learning: **The Provide State** From Possibilities to Practice



### **State Space of a Problem**







#### **Interaction Network as a Construct**





Innovations in Learning:



#### **Interaction Network as a Construct**













#### **Rule-using Problem: Multiple Paths to a Goal**





## Innovations in Learning: **The Provide Active State** From Possibilities to Practice









#### **Multiple Paths and Multiple Goals**







#### Not all paths observed







