Creating Infinitely Adaptable Courseware

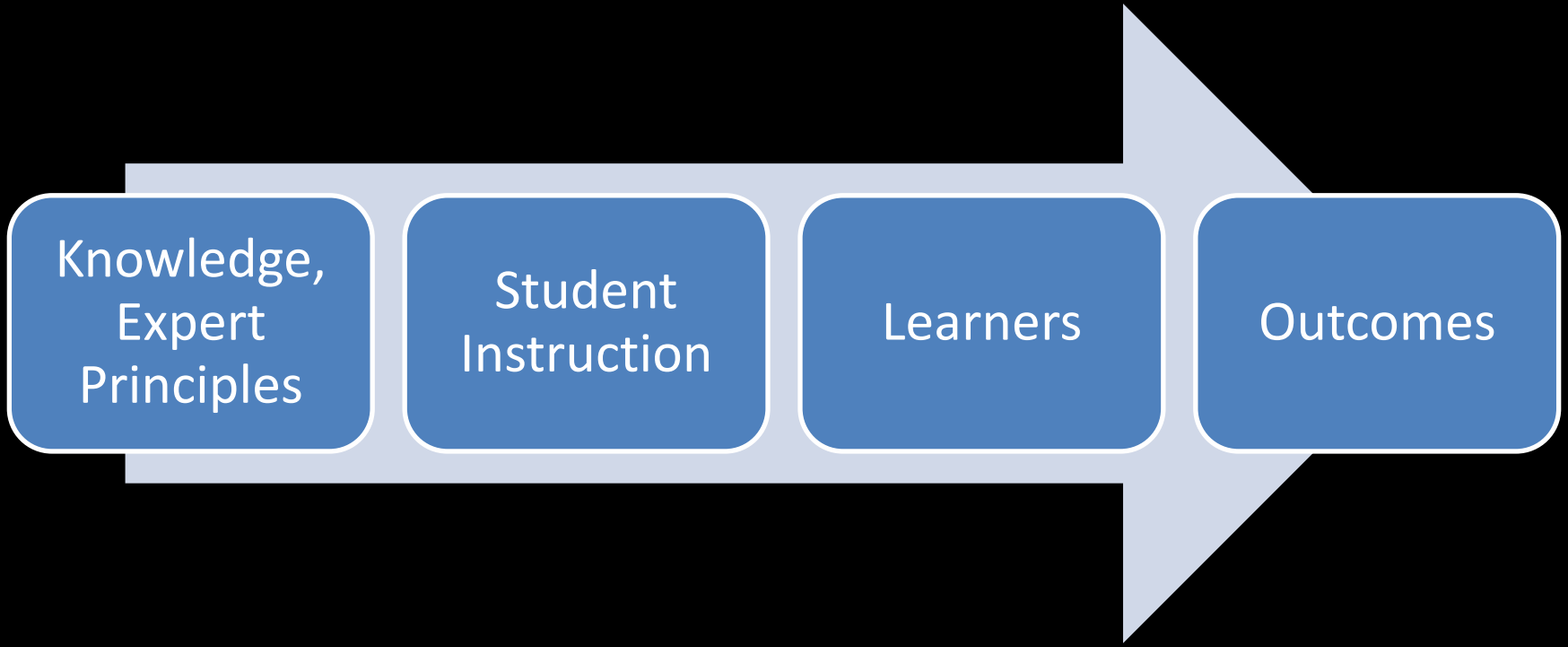
Zoran Popović
zoran@cs.washington.edu

Center for Game Science
University of Washington

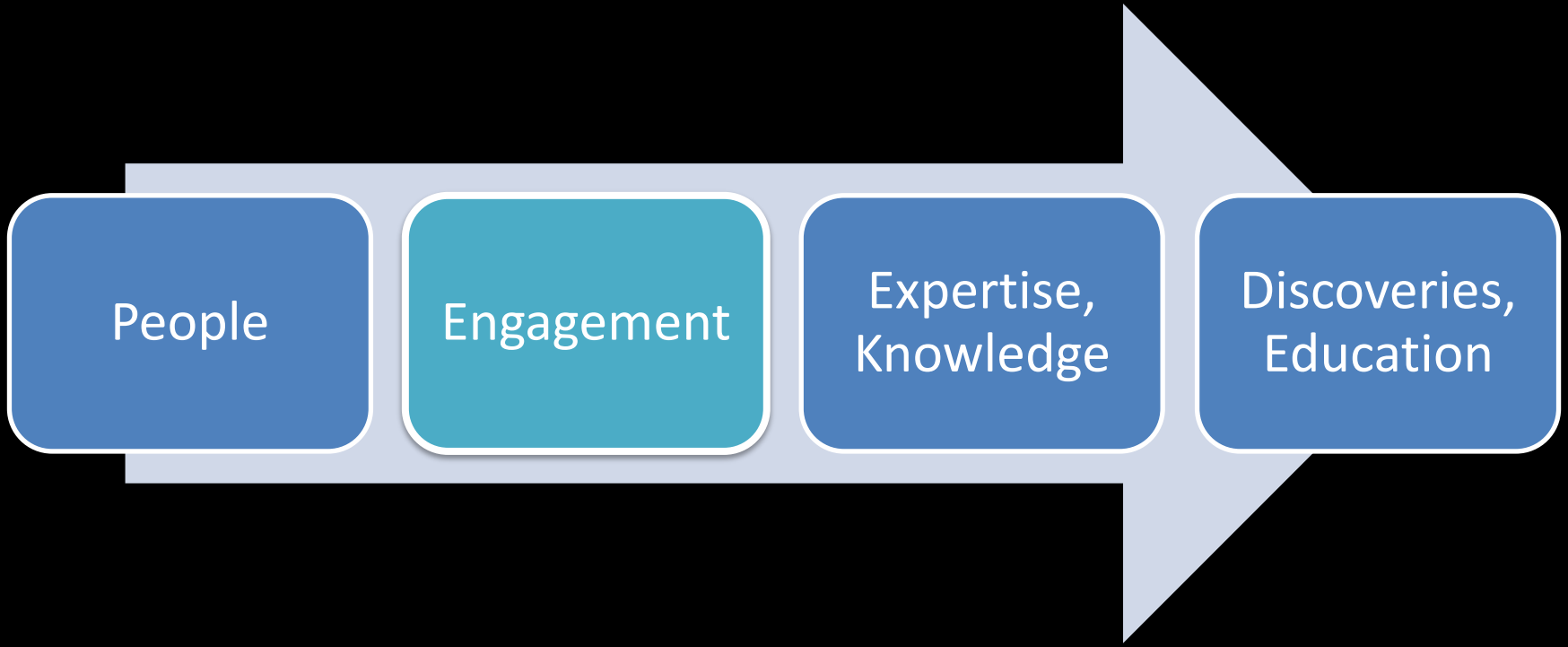
The Challenge

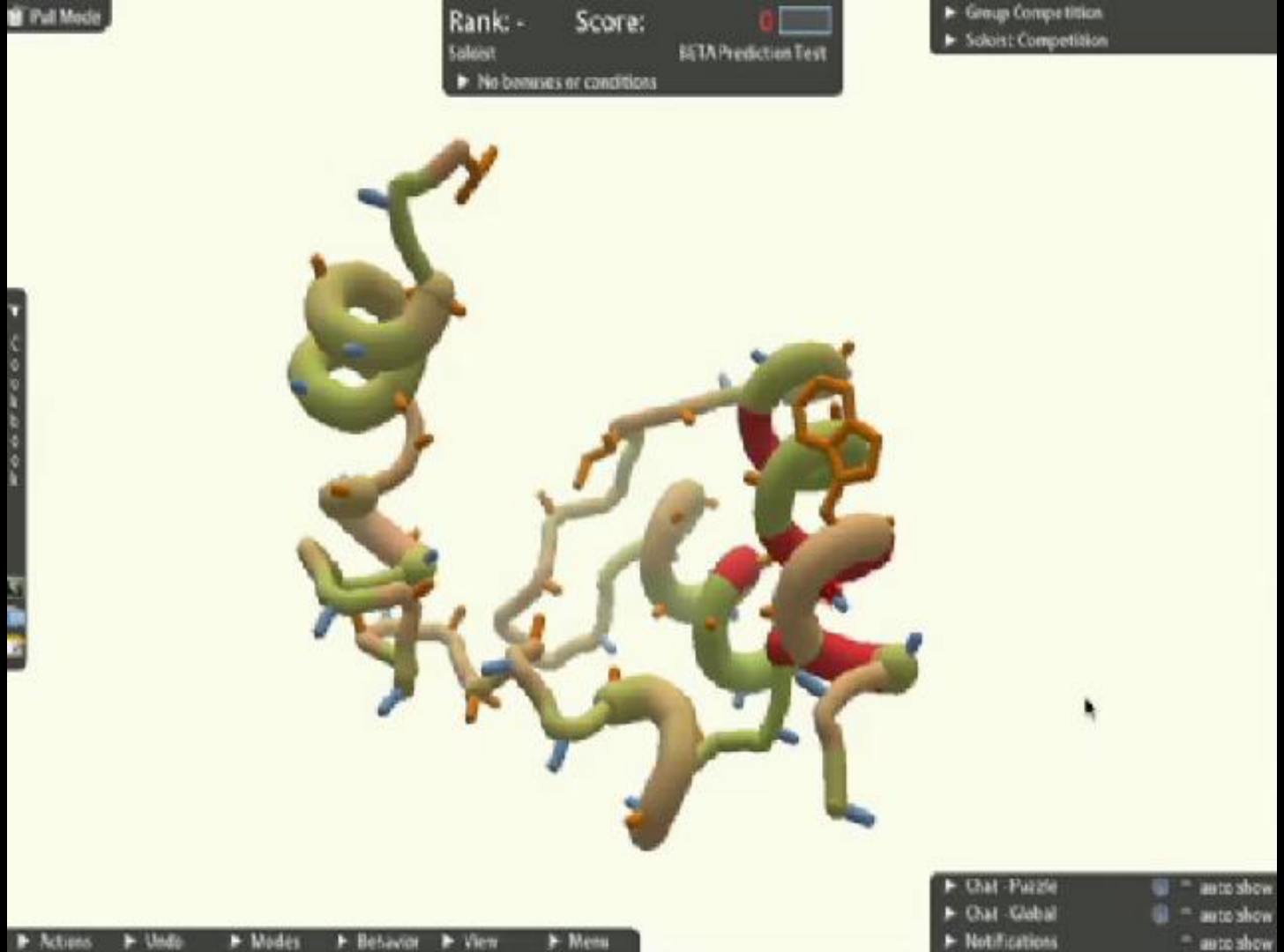
A new learning environment
that creates inspired learners
and world-class experts

Standard approach



Engaged Mastery




Pull Mode
Rank: -
Score:
0
Soloist
BETA Prediction Test
No bonuses or conditions
Group Competition
Solos: Competition
Chat - Puzzle
Chat - Global
Notifications
auto show
auto show
auto show
Actions
Undo
Modes
Behavior
View
Menu

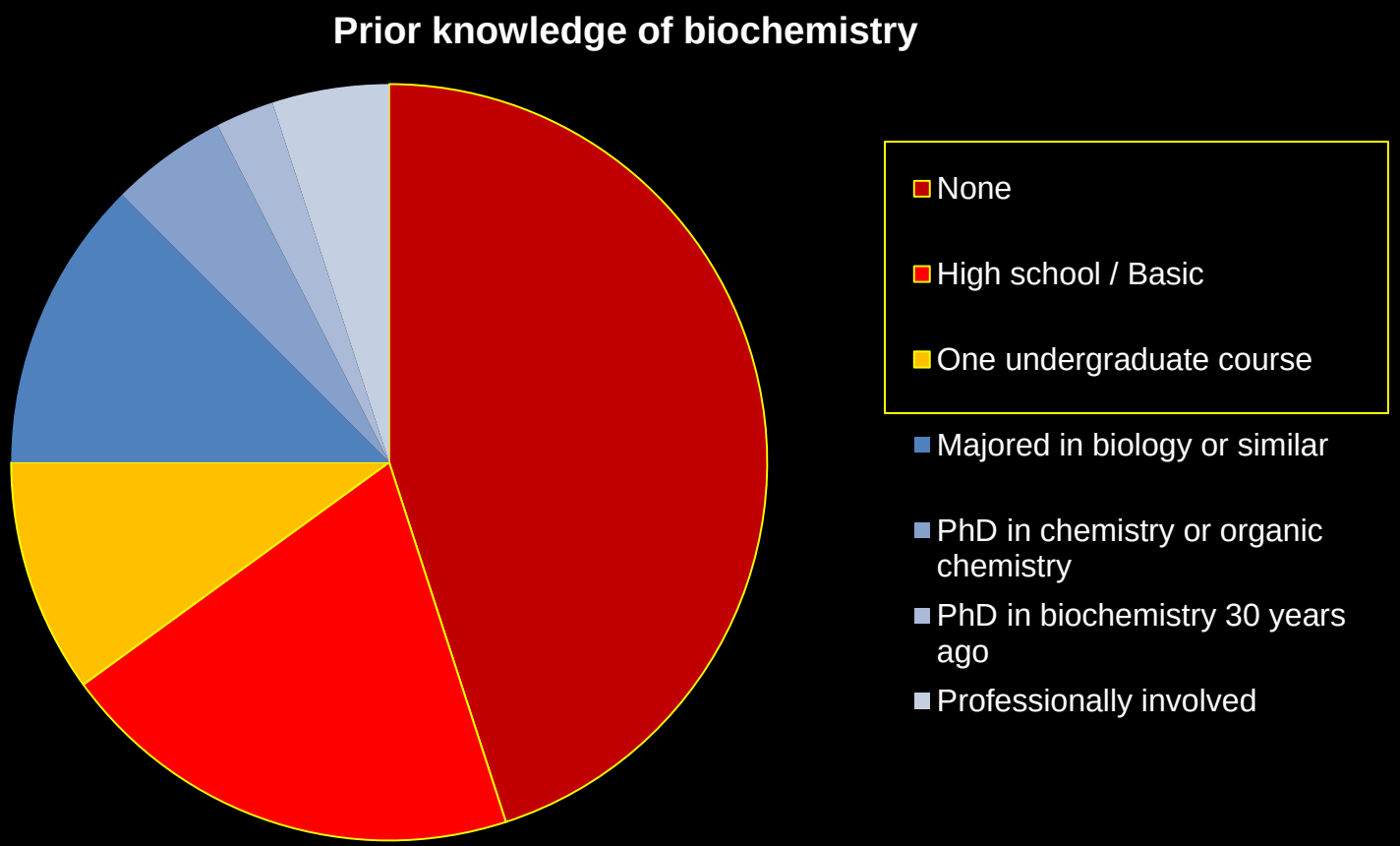

nature
CHEMISTRY IN MOTION
Attosecond snapshots reveal dynamics of valence electrons
HEART DISEASE
Scanning for serum lipid genes
CITIZEN SCIENCE
Crowd-based supercomputing
OCEAN MONITORING
Tap into submarine cables
NATURE.COM
Marine biology


nature biotechnology


nature structural & molecular biology
Competing for RNAs

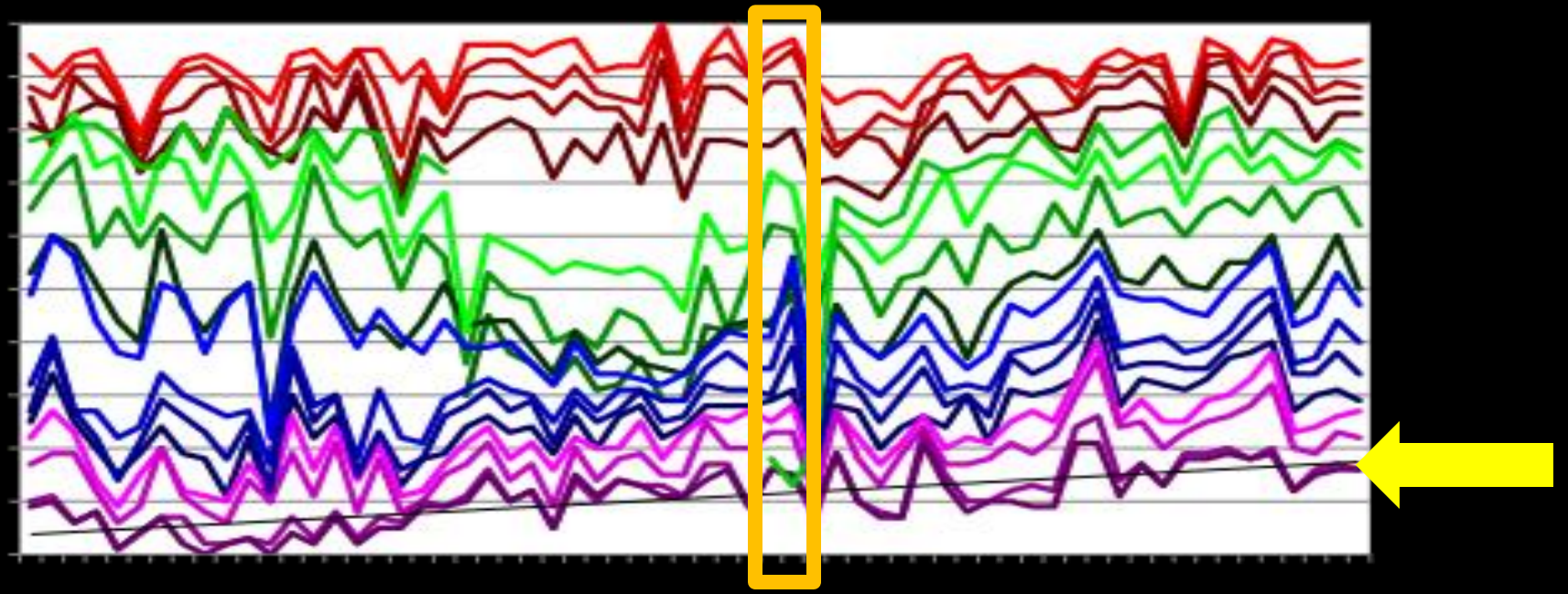

PNAS

Game developed experts



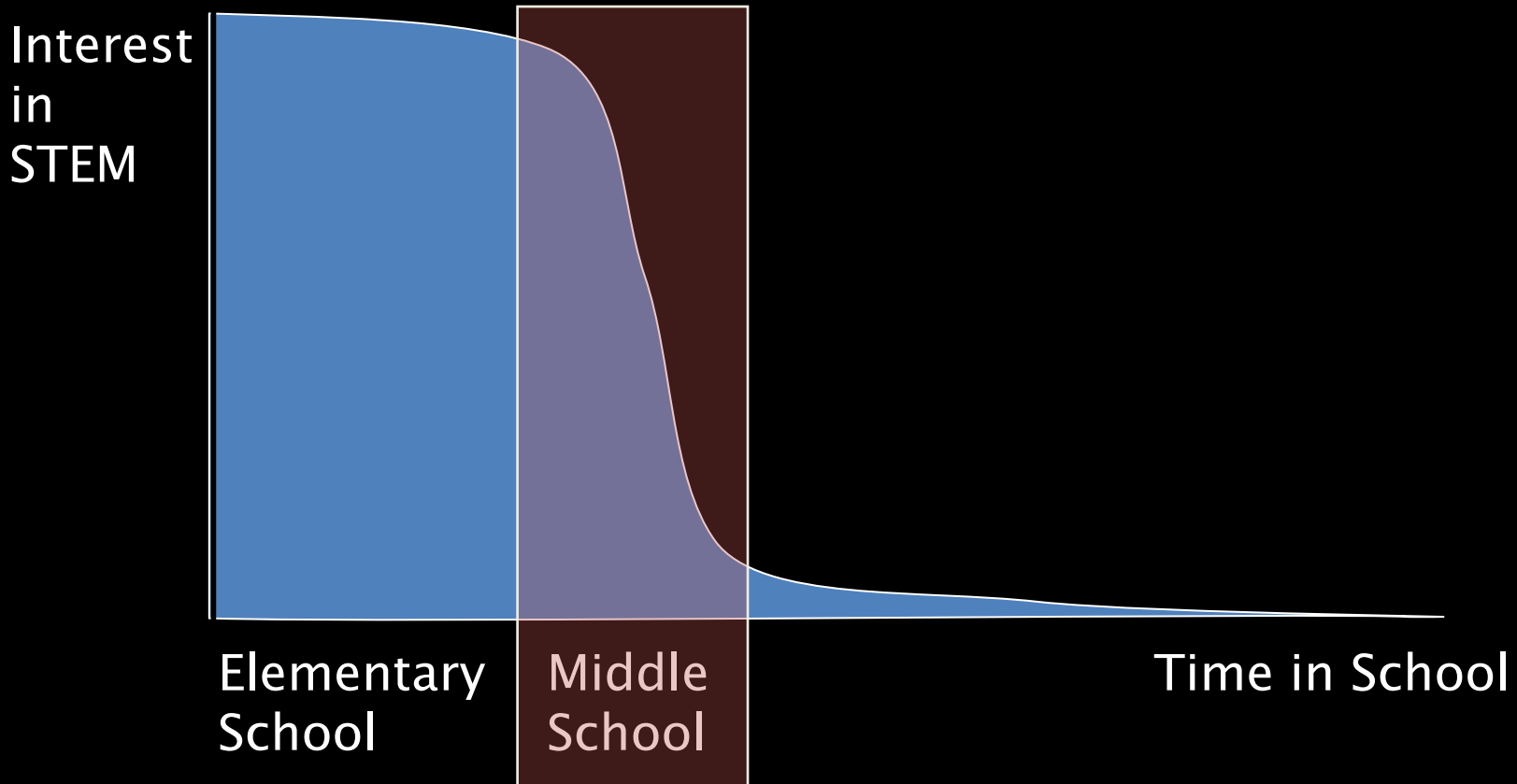
Data-driven Game Evolution

refinement



Optimize for Engagement and Mastery

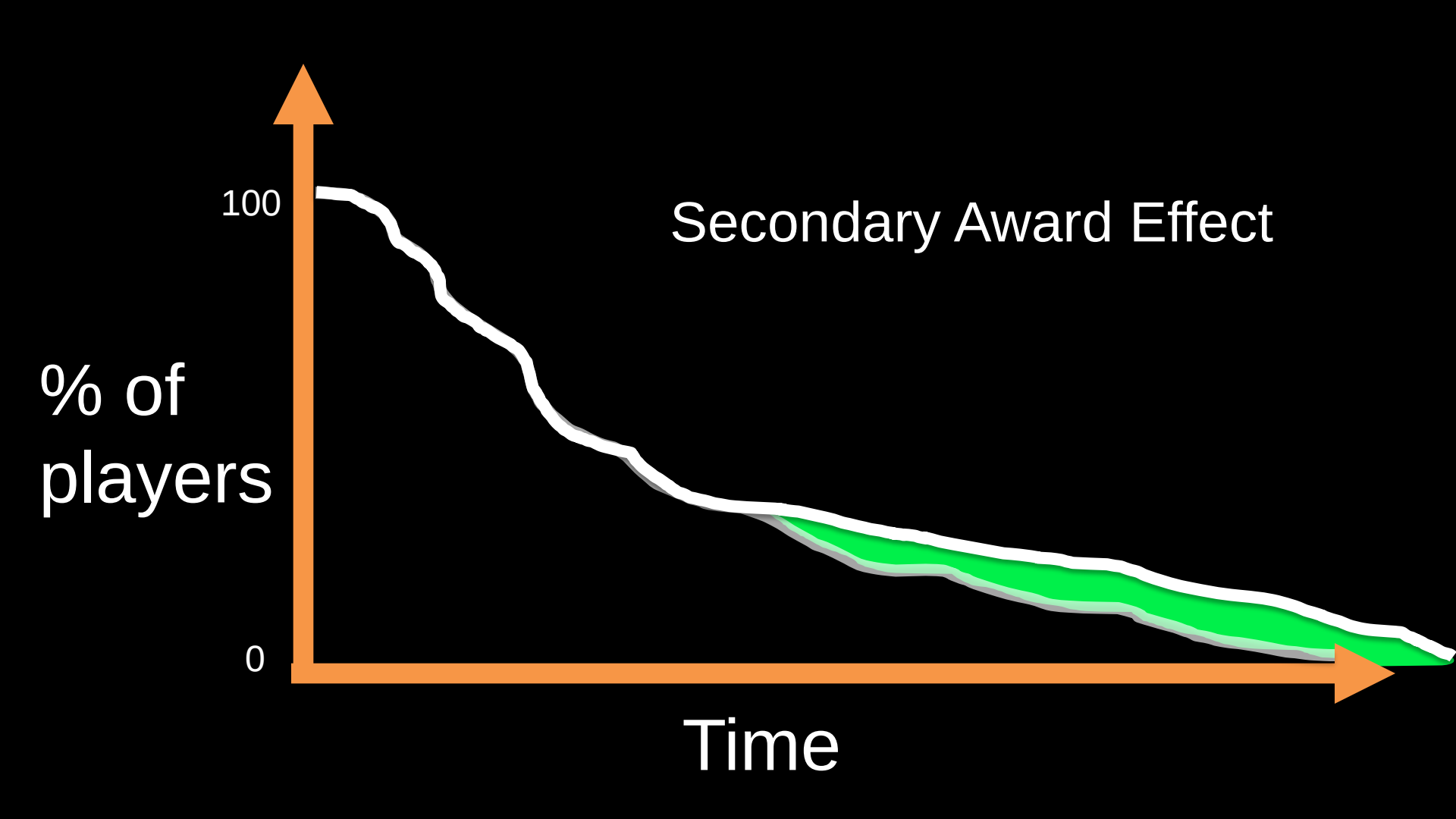
Importance of Early Math

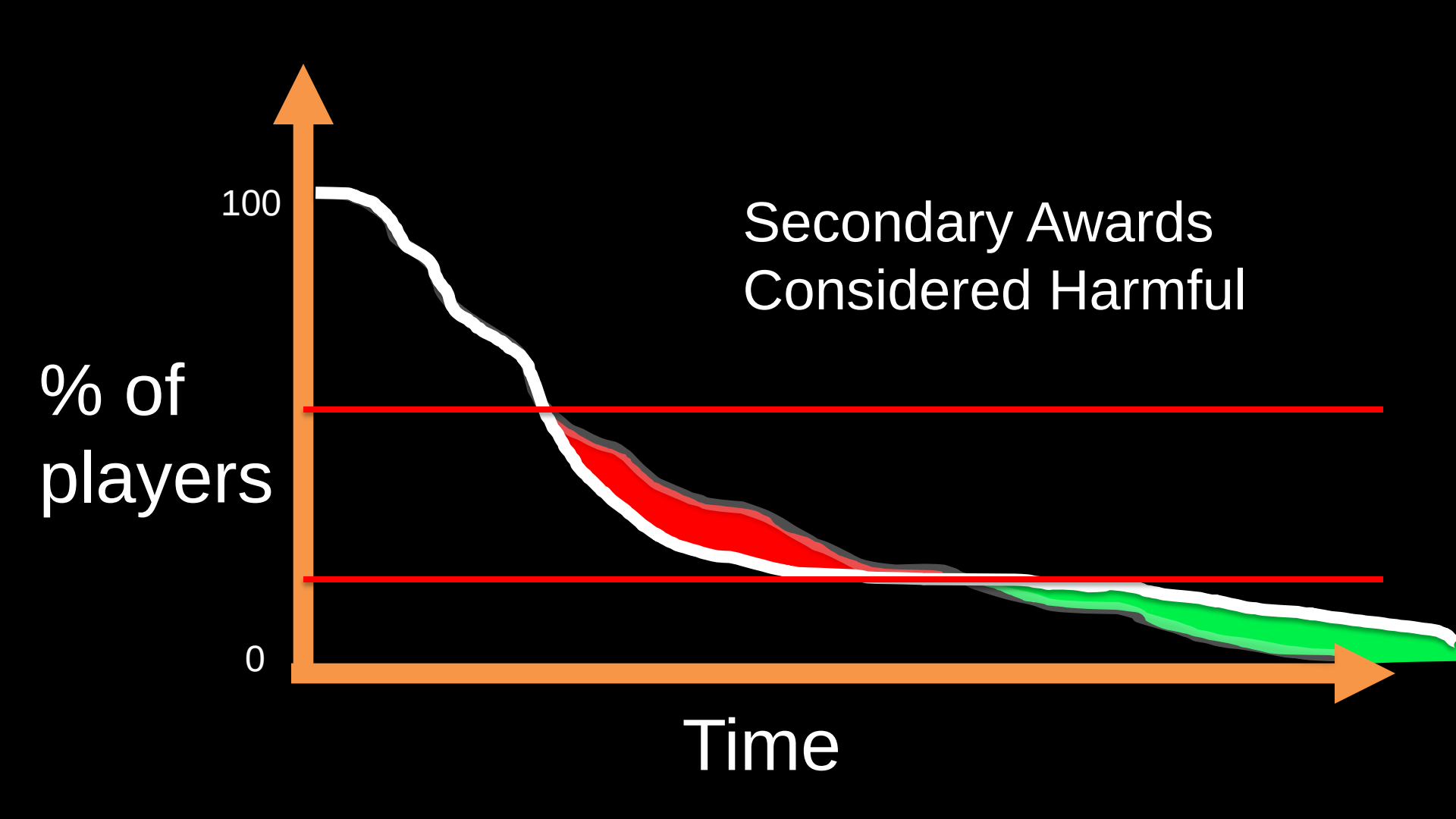



Menu
3
4
Smallest Number
Wins
Rival
Last
Turn


0/8
10

Games for Massive Data-gathering to Optimize Learning Pathways


100
0
% of players
Secondary Award Effect
Time

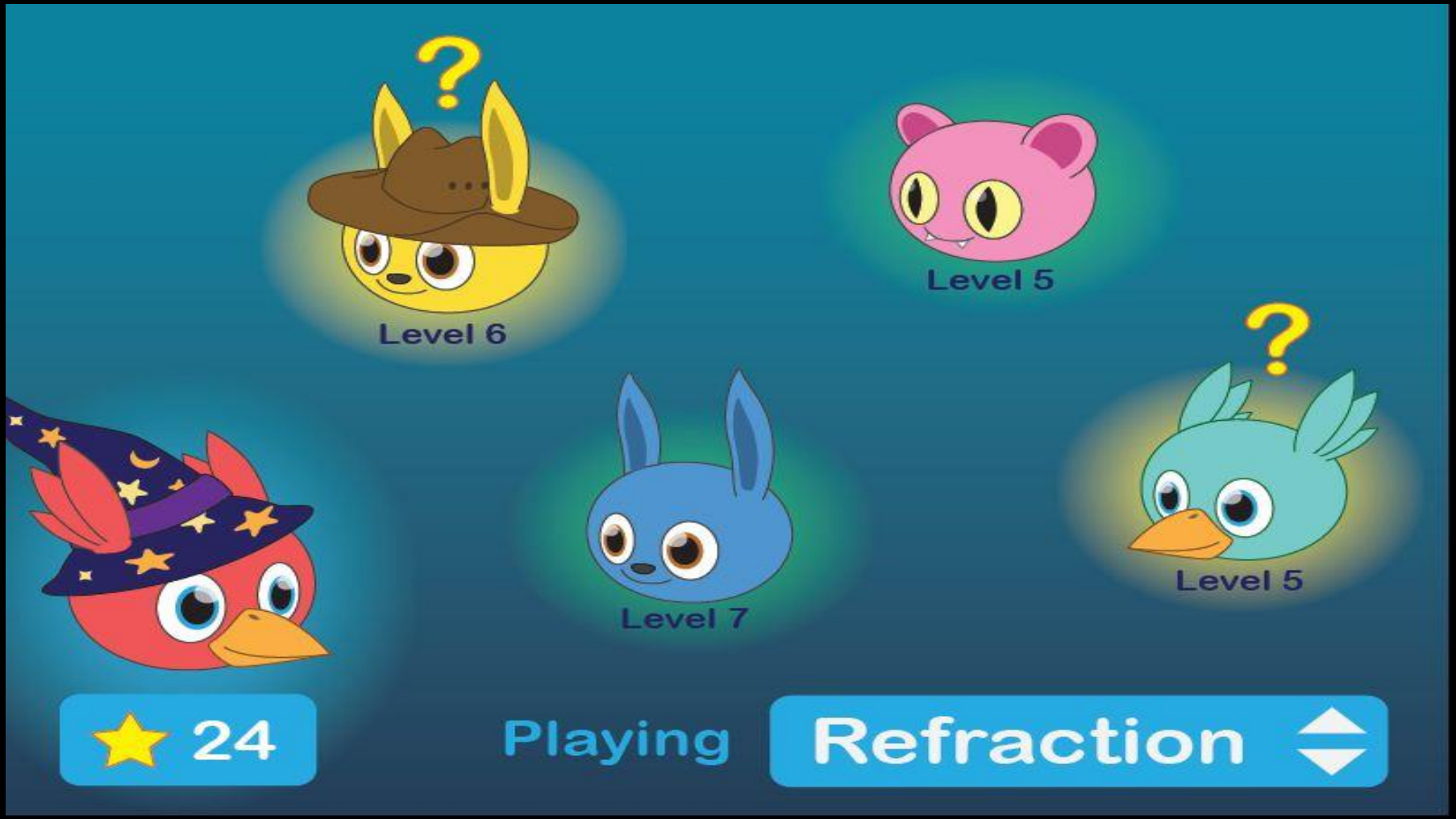

Secondary Awards
Considered Harmful
% of
players
100
0
Time

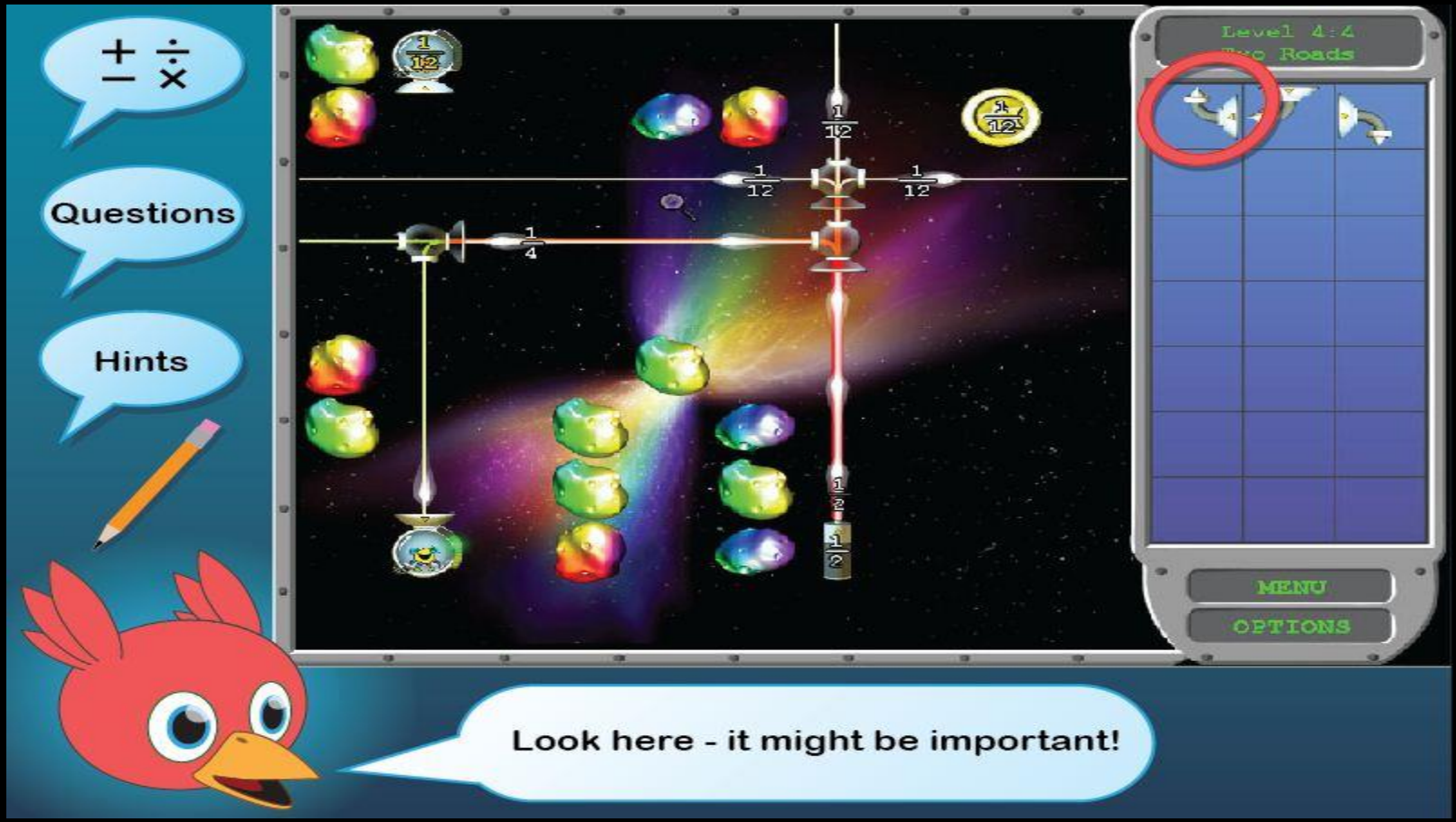
Extrinsic Motivation: short term effect

Long term engagement: Self-identification

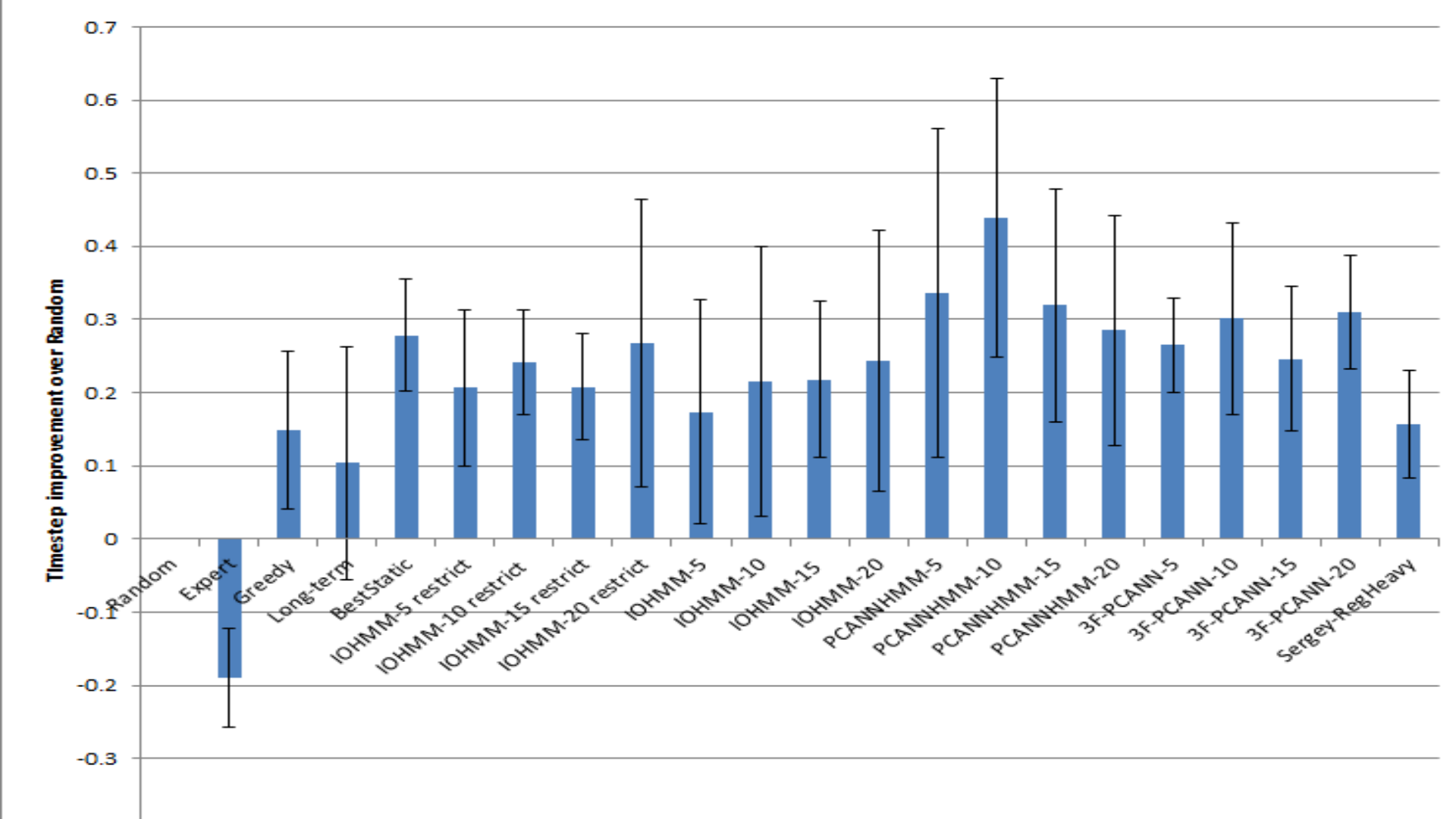
Create an exam

Game designer levels


Level 6
Level 5
Level 7
Level 5
24
Playing
Refraction


Questions
Hints
Level 4:4
Two Roads
MENU
OPTIONS
Look here - it might be important!

Specialized Pathways to Mastery


Timestep improvement over Random
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Random
Expert
Greedy
Long-term
BestStatic
IOHMM-5 restrict
IOHMM-10 restrict
IOHMM-15 restrict
IOHMM-20 restrict
IOHMM-5
IOHMM-10
IOHMM-15
IOHMM-20
PCANNHMM-5
PCANNHMM-10
PCANNHMM-15
PCANNHMM-20
3F-PCANN-5
3F-PCANN-10
3F-PCANN-15
3F-PCANN-20
Sergey-RegHeavy

Infinitely Adaptable Courseware

Engaged Learning Platform

Courseware that optimizes for each learner by optimizing mastery and engagement

1-8 grade Math

PA6-1: Increasing Sequences

In an **increasing sequence**, each number is greater than the one before it.

Deborah wants to continue the number pattern: 6 , 8 , 10 , 12 , ?

She finds the **difference** between the first two numbers:

(2) 6 , 8 , 10 , 12 , ?

She finds that the difference between the other numbers in the pattern is also 2. So the pattern was made by adding 2:

(2) (2) (2) 6 , 8 , 10 , 12 , ?

To continue the pattern, Deborah adds 2 to the last number in the sequence.

The final number in the pattern is 14:

(2) (2) (2) (2) 6 , 8 , 10 , 12 , 14

---

1. Extend the following patterns. Start by finding the gap between the numbers.

a) ○ ○ ○ ○ ○ 2 , 5 , 8 , ___ , ___ , ___

b) ○ ○ ○ ○ ○ 1 , 7 , 13 , ___ , ___ , ___

c) ○ ○ ○ ○ ○ 2 , 7 , 12 , ___ , ___ , ___

d) ○ ○ ○ ○ ○ 4 , 8 , 12 , ___ , ___ , ___

e) ○ ○ 1 , 6 , 11 , ___ , ___ , ___

f) ○ ○ 4 , 10 , 16 , ___ , ___ , ___

g) ○ ○ 2 , 12 , 22 , ___ , ___ , ___

h) ○ ○ 7 , 15 , 23 , ___ , ___ , ___

i) ○ ○ 31 , 34 , 37 , ___ , ___ , ___

j) ○ ○ 92 , 98 , 104 , ___ , ___ , ___

k) ○ ○ 12 , 23 , 34 , ___ , ___ ,

l) ○ ○ 0 , 8 , 16 ,

PA6-5: Introduction to T-tables

Claude creates an **increasing pattern** with squares. He records the number of squares in each figure in a chart or T-table. He also records the number of squares he adds each time he makes a new figure:

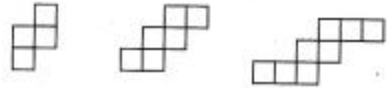


Figure 1 Figure 2 Figure 3

Figure	# of Squares
1	4
2	6
3	8

(2) (2) ← Number of squares added each time

The number of squares in the figures are 4, 6, 8, ...

Claude writes a rule for this number pattern:

RULE: Start at 4 and add 2 each time.

---

1. Claude makes other increasing patterns with squares.
   How many squares does he add to make each new figure?
   Write your answer in the circles provided. Then write a rule for the pattern:

a)

Figure	Number of Squares
1	2
2	8
3	14

Rule:

b)

Figure	Number of Squares
1	3
2	9
3	15

Rule:

c)

Figure	Number of Squares
1	1
2	6
3	11

Rule:

d)

Figure	Number of Squares
1	1

e)

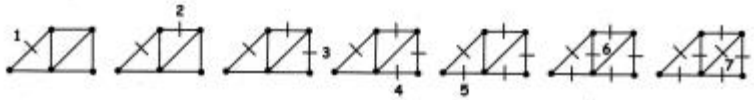
Figure	Number of Squares
1	5

f)

Figure	Number of Squares
1	11

PA6-6: T-tables

1. Count the number of line segments (lines that join pairs of dots) in each set of figures by marking each line segment as you count, as shown in the example:
HINT: Count around the outside of the figure first.

Example: 

a)  ____

b)  ____

c)  ____

2. Continue the pattern below, then complete the chart:

Figure 1 

Figure 2 

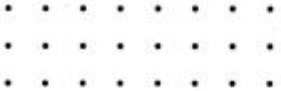
Figure 3 

Figure	Number of Line Segments
1	
2	
3	

a) How many line segments would Figure 4 have? _____

b) How many line segments would you need to make a figure with 5 triangles? _____

3. Continue the pattern below, then complete the chart:

Figure 1 

Figure 2 

Figure	Number of Triangles	Number of Line Segments

PA6-18: Finding Rules for Patterns – Part II

1. In each pattern below, the number of *shaded* blocks increases directly with the Figure Number. The *total* number of blocks, however, does not increase directly.

   i) Write a rule for the number of *shaded* blocks in each sequence.
   ii) Write a rule for the *total number* of blocks in each sequence.

a)

Figure 1 Figure 2 Figure 3

Rule for the number of shaded blocks:

2 × Figure Number

Rule for the total number of blocks:

2 × Figure Number + 1

b)

Figure 1 Figure 2 Figure 3

Rule for the number of shaded blocks:

Rule for the total number of blocks:

c)

Figure 1 Figure 2 Figure 3

Rule for the number of shaded blocks:

Rule for the total number of blocks:

d)

Figure 1 Figure 2 Figure 3

Rule for the number of shaded blocks:

Rule for the total number of blocks:

e) Rule for the number of shaded blocks:

Rule for the total number of blocks:

Figure 1 Figure 2 Figure 3

2. Draw or build a sequence of figures that might go with the following tables.

NS3-9: Comparing and Ordering Numbers

1. Write the **value** of each digit. Then complete the sentence.

a) 3 7 4 7

_____ is greater than _____

b) 6 4 7 5 4 7

_____ is greater than _____

2. Circle the pair of digits that are different in each pair of numbers.
Then write the greater number in the box.

a) 475 / 465 — 475

b) 360 / 260 — ____

c) 852 / 858 — ____

d) 136 / 126 — ____

3. Read the numbers from left to right.
Circle the first pair of digits you find that are different. Then write the greater number in the box.

a) 583 / 597 — 597

b) 629 / 654 — ____

c) 576 / 603 — ____

d) 432 / 431 — ____

e) 384 / 597 — ____

f) 906 / 904 — ____

g) 875 / 869 — ____

h) 238 / 221 — ____

4. Circle the greater number.

a) 111 or 311

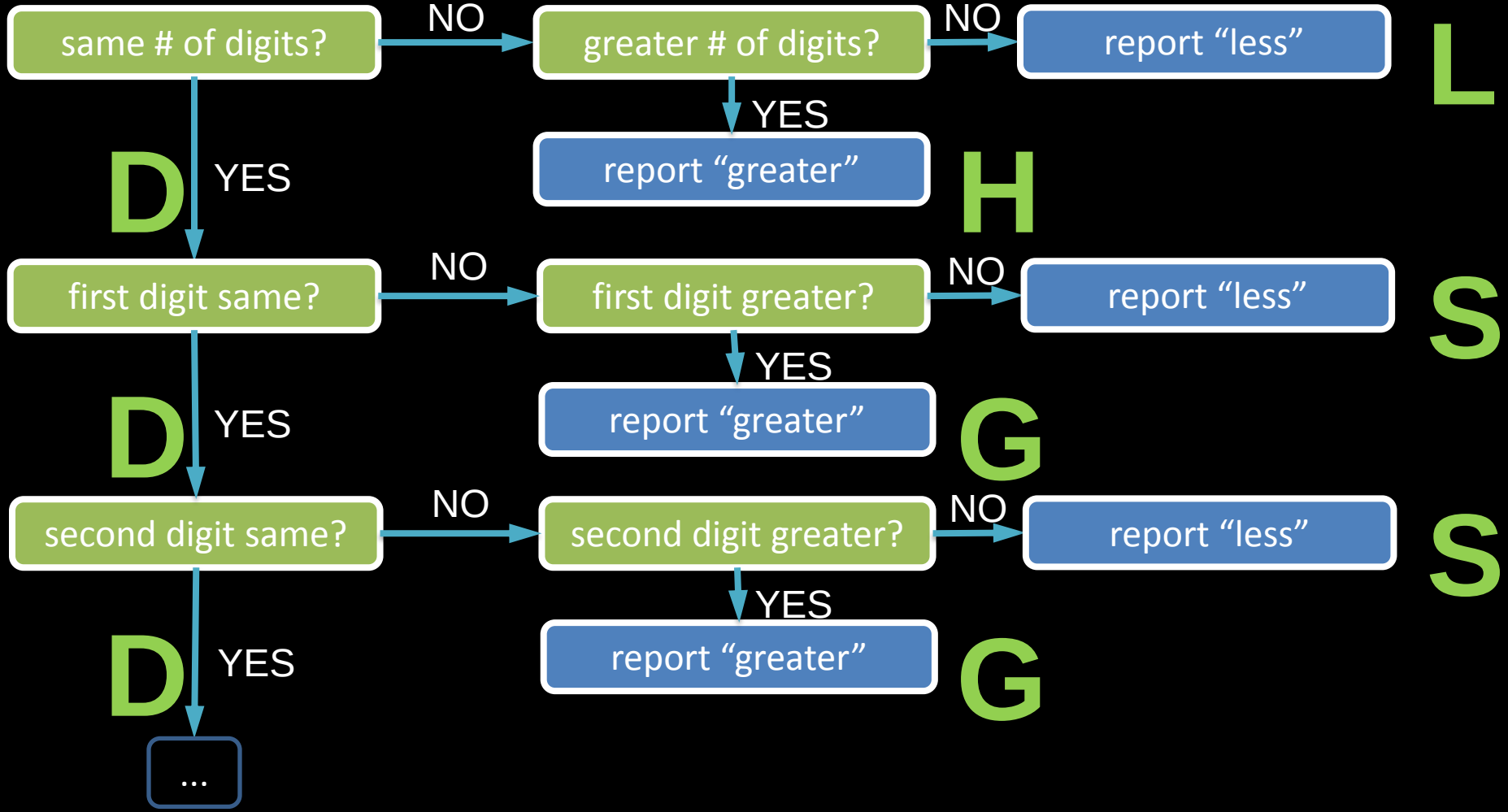
b) 625 or 525

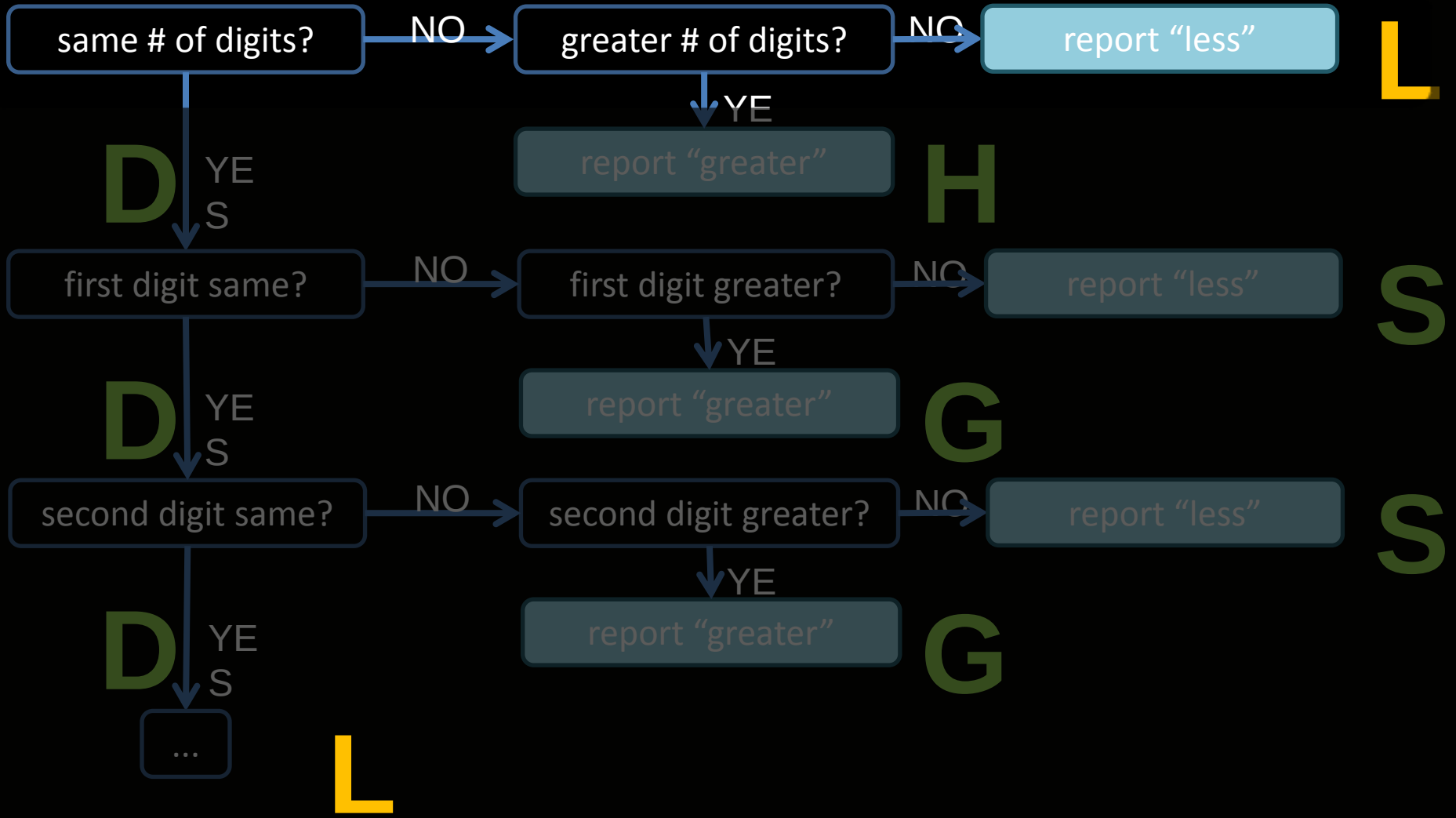
c) 321 or 721

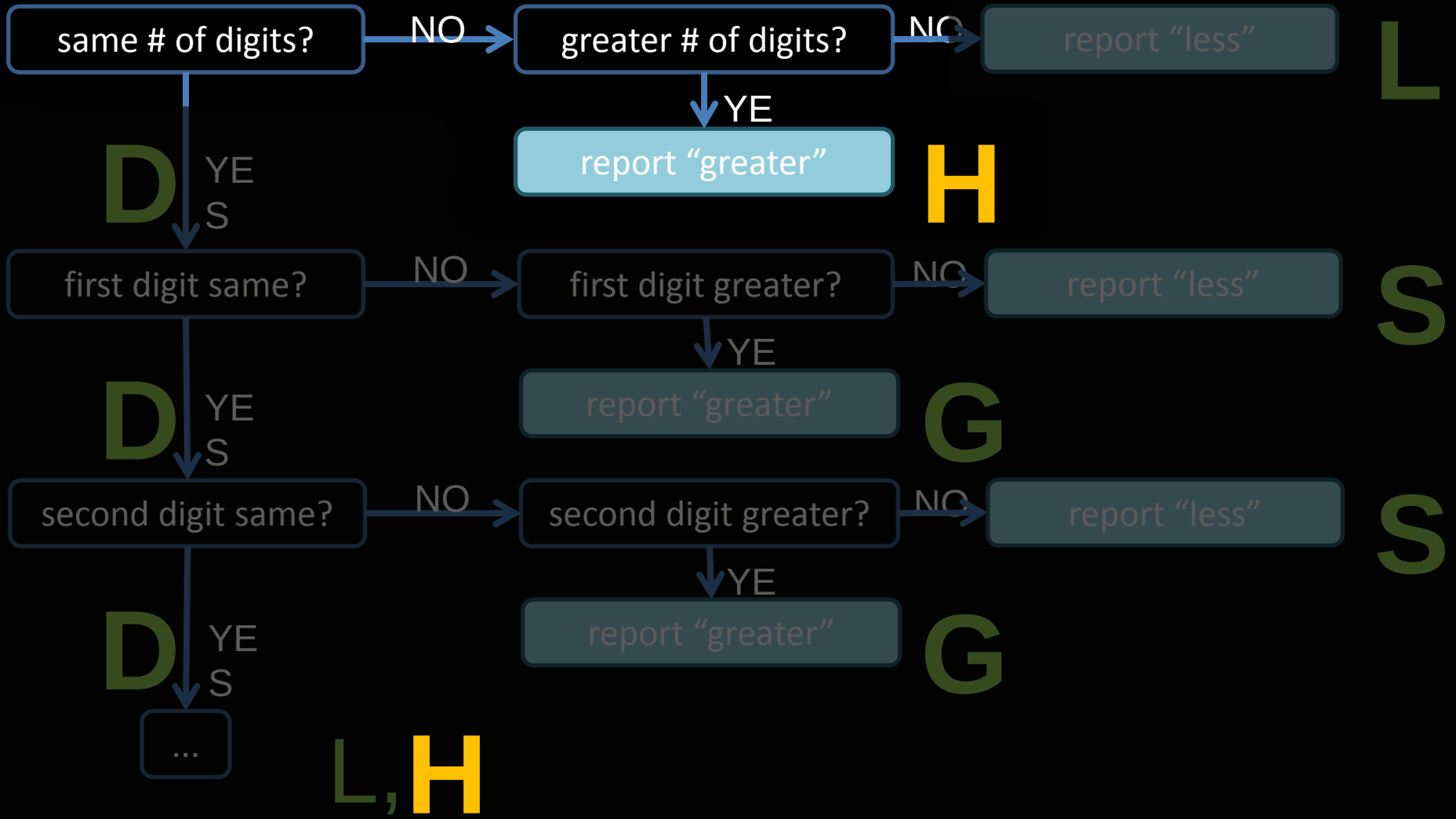
d) 843 or 867

e) 480 or 412

f) 219 or 220


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YES
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YES
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YES
report “greater”
G
D
YES
...


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
...
L


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YE
S
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
...
L, H


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YE
S
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
...
L, H, DS


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
...
L, H, DS, DG


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YE
S
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YE
S
...
L, H, DS, DG, DDS


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
...
L, H, DS, DG, DDS, DDG…


same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
...
Compare 313 to 324.

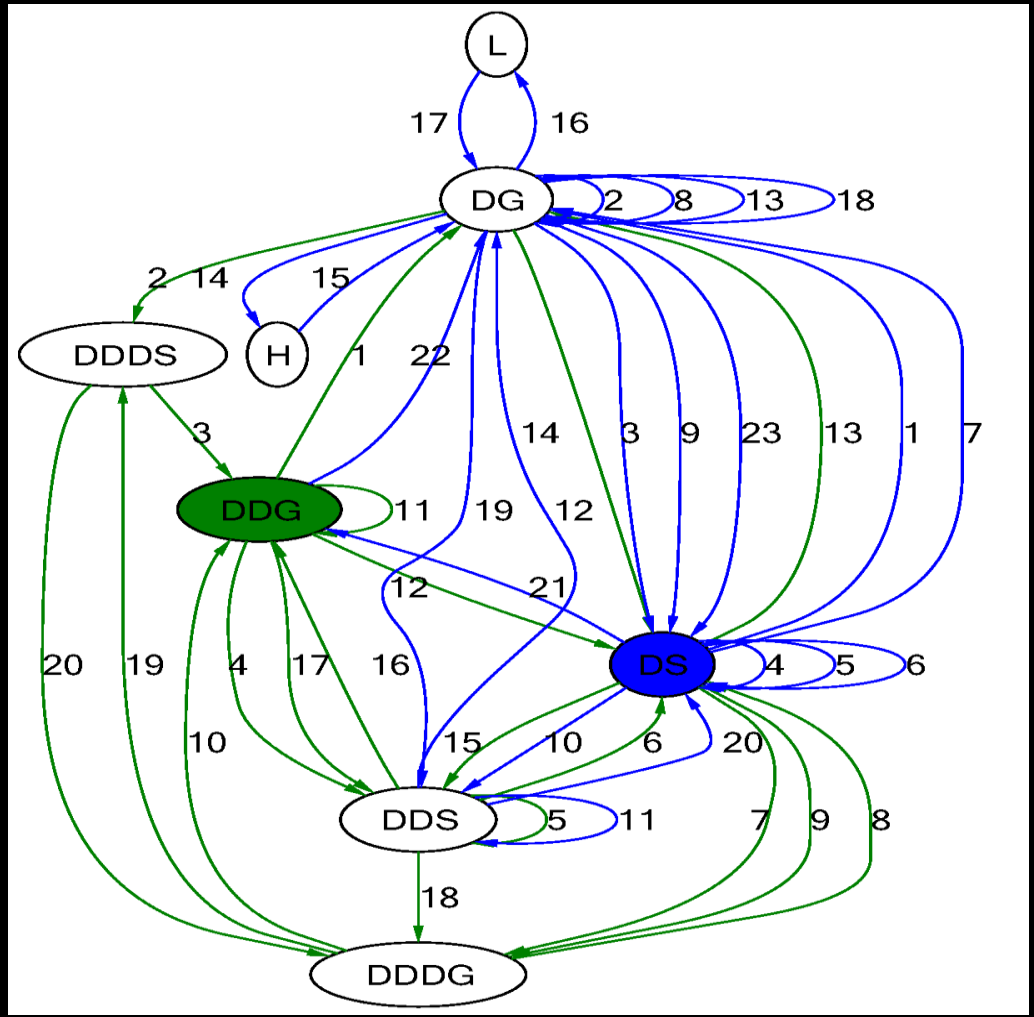

same # of digits?
NO
greater # of digits?
NO
report “less”
L
YE
report “greater”
H
D
YES
first digit same?
NO
first digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
second digit same?
NO
second digit greater?
NO
report “less”
S
YE
report “greater”
G
D
YES
...
Compare 313 to 324.

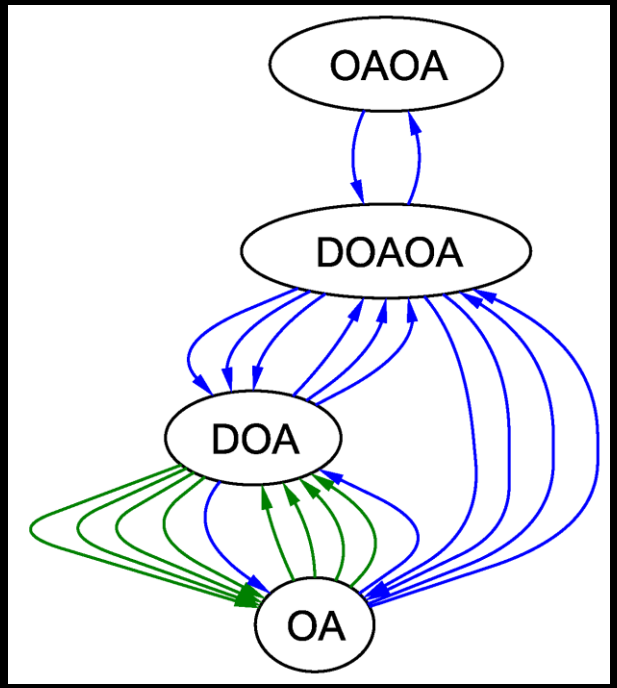
What can we do with traces?

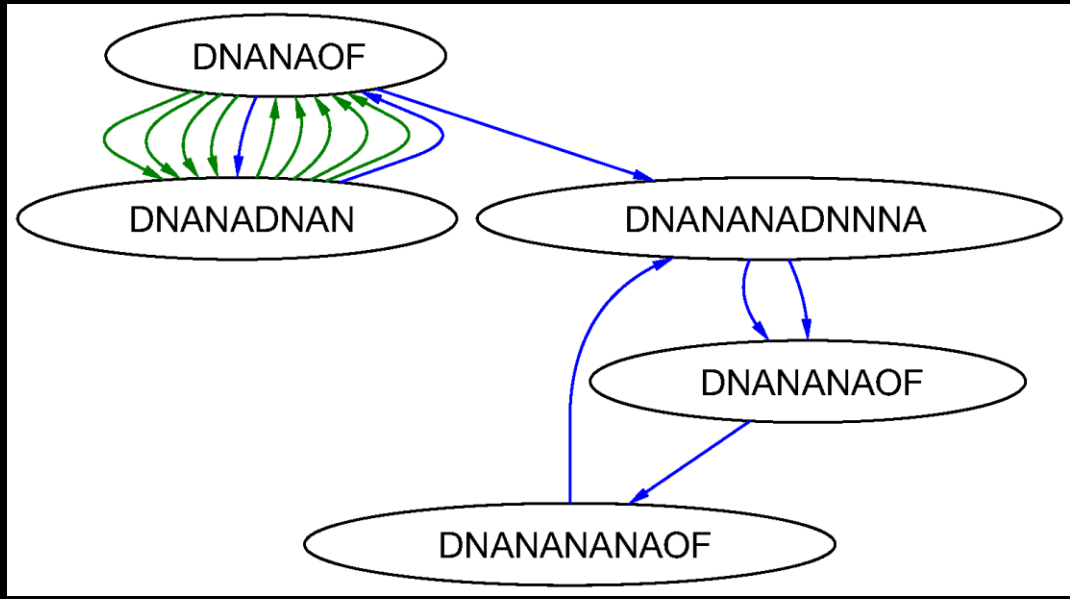
- Rank their difficulty
- Analyze and compare progressions
- Synthesize new progressions

JUMP Math

Singapore Math







Fraction Addition and Subtraction

Integer Addition

Problem
Addition: Standard
Addition: Counting On
Division: Repeated Subtraction Full
Division: Repeated Subtraction Remainder Only
Fraction Division
Fraction Multiplication
Fraction Reciprocal
Fraction Reduction: Successive Division
GCF: Euclid’s Algorithm
GCF: Successive Division
GCF: Simultaneous Division
Matrix Addition
Matrix Subtraction
Matrix Scalar Multiplication
Pattern Continuation: Addition
Pattern Continuation: Subtraction
Pattern Continuation: Explicit Addition
Pattern Continuation: Explicit Subtraction
Prime Factorization
Subtraction: Counting Back

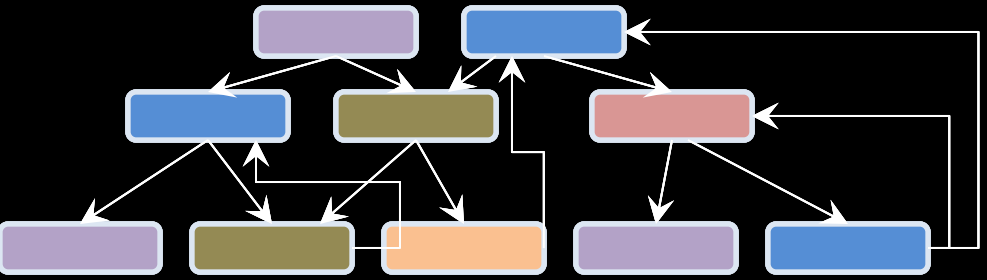
Conceptual Problems

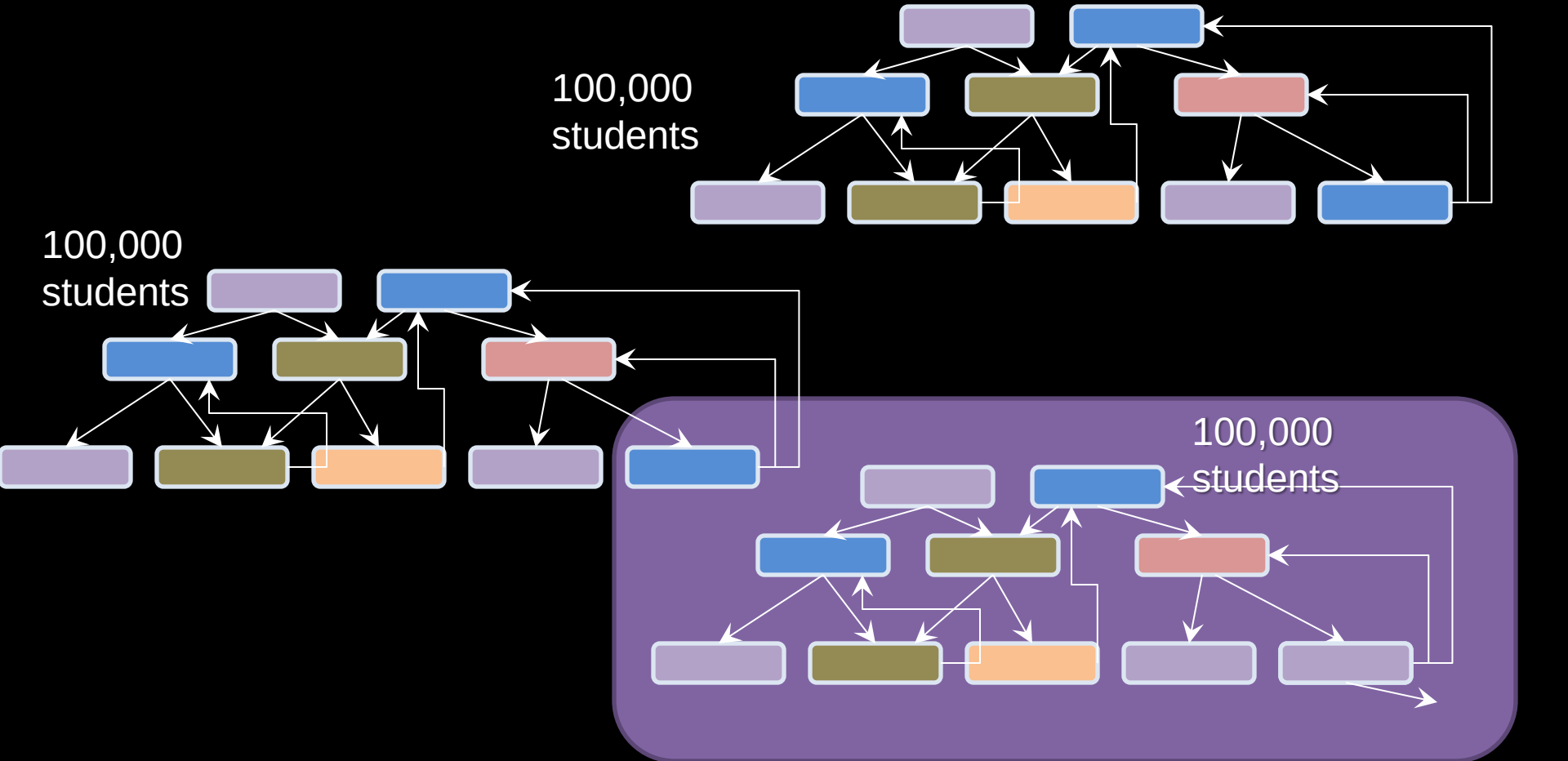
- Algebra
- Geometry proofs
- Solving unknown problems

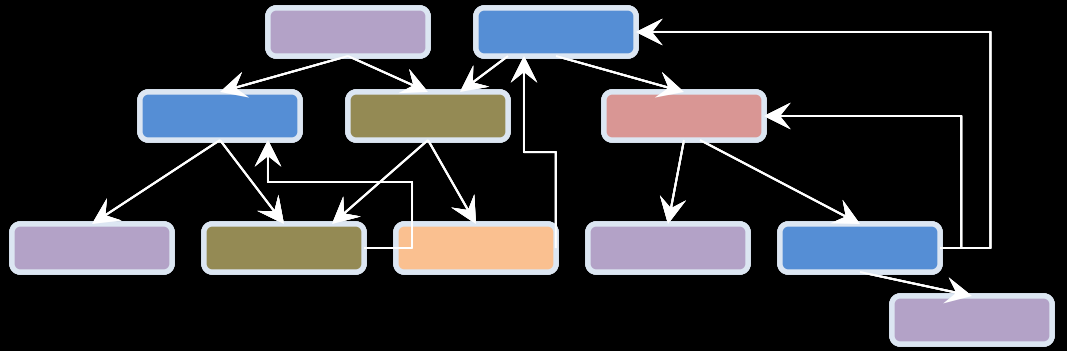
Complexity Grows Exponentialy

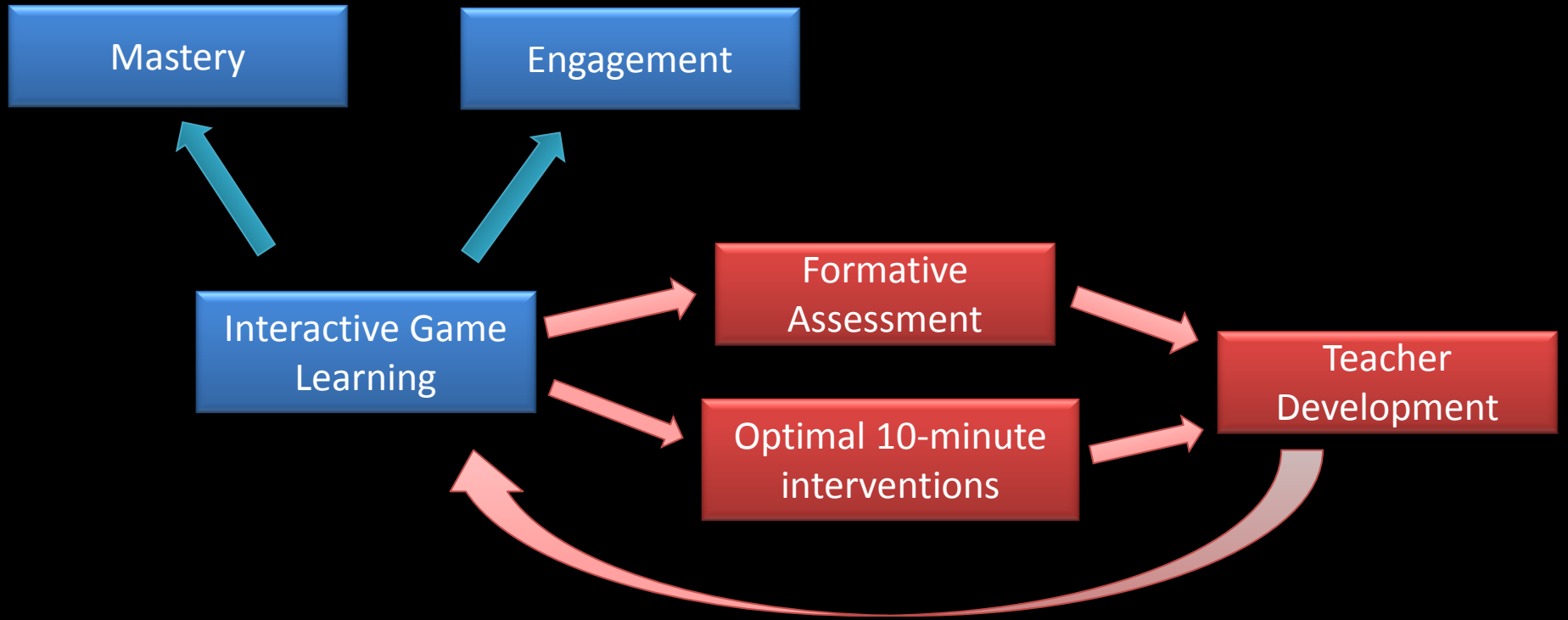
Personalized Algebra

In-vivo courseware adaptation

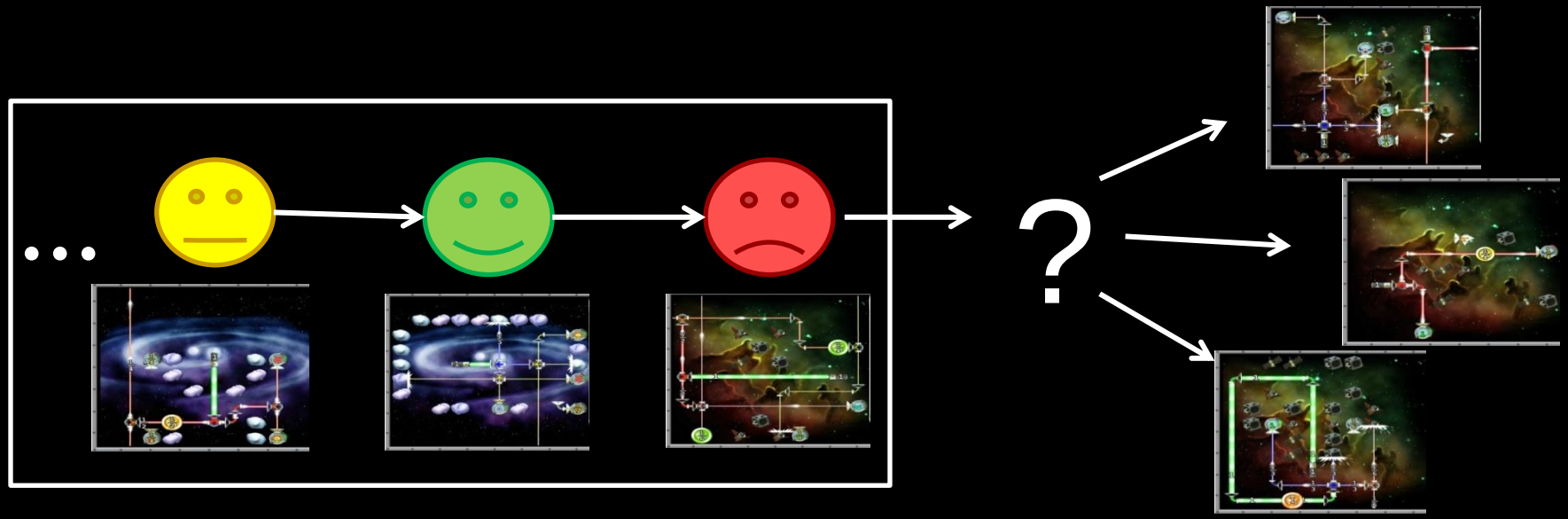



100,000
students
100,000
students
100,000
students

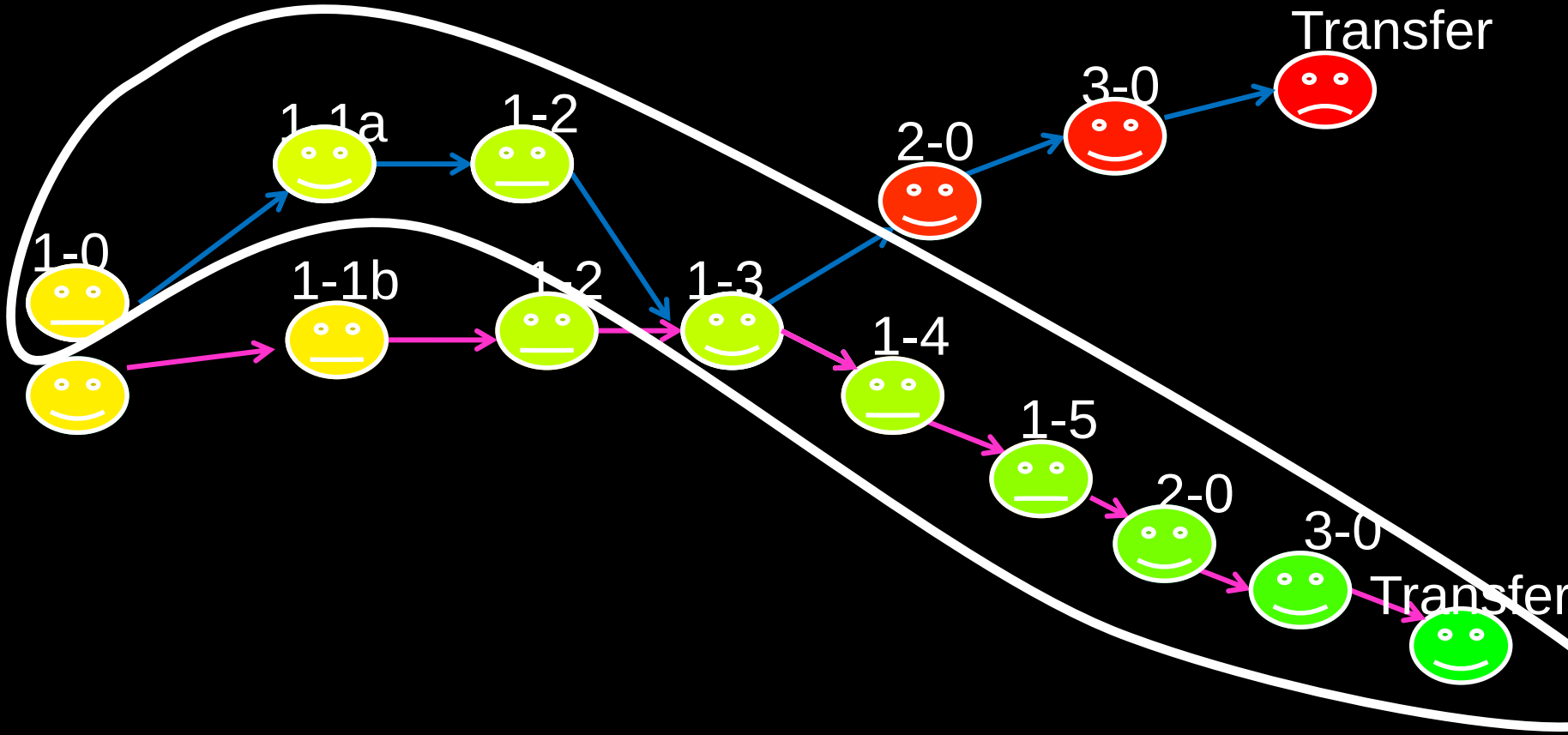


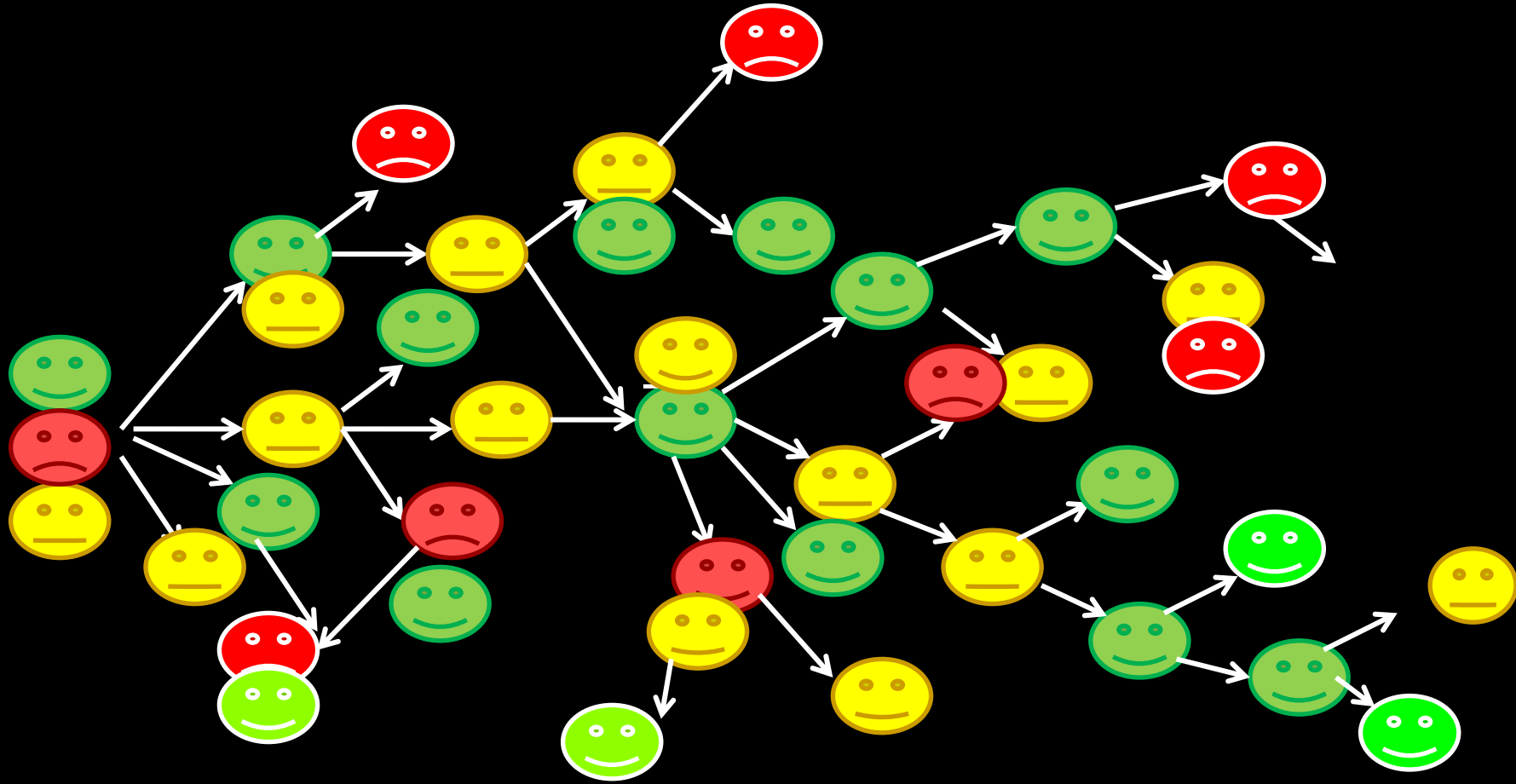

Mastery
Engagement
Interactive Game Learning
Formative Assessment
Optimal 10-minute interventions
Teacher Development

Reinforcement Learning



Goal: Maximize student's learning & engagement


Transfer
3-0
2-0
1-1a
1-2
1-0
1-1b
1-2
1-3
1-4
1-5
2-0
3-0
Transfer



Scaffolding RL experiments

- Dwell Time (Time on Task)

A	A	A	B	B	B	AB	AB
A	B	AB	C	ABC	D	ABCD	

- Concept layering

… ABC	D	AD	BD	CD	ABD	ACD	ABCD
… ABC	D	ABCD	E	ABCDE			

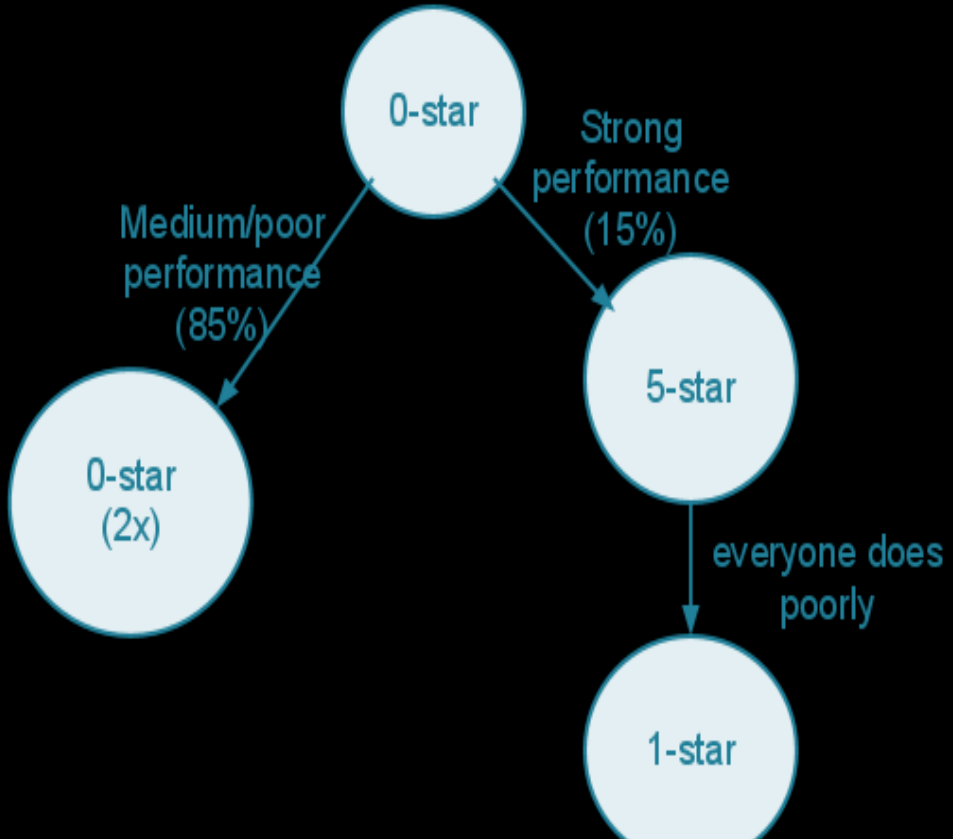
- Concept Ordering

B	BC	A	ABC			
AB	C	ABC	F	D	FD	ABCDF

Key RL experiments

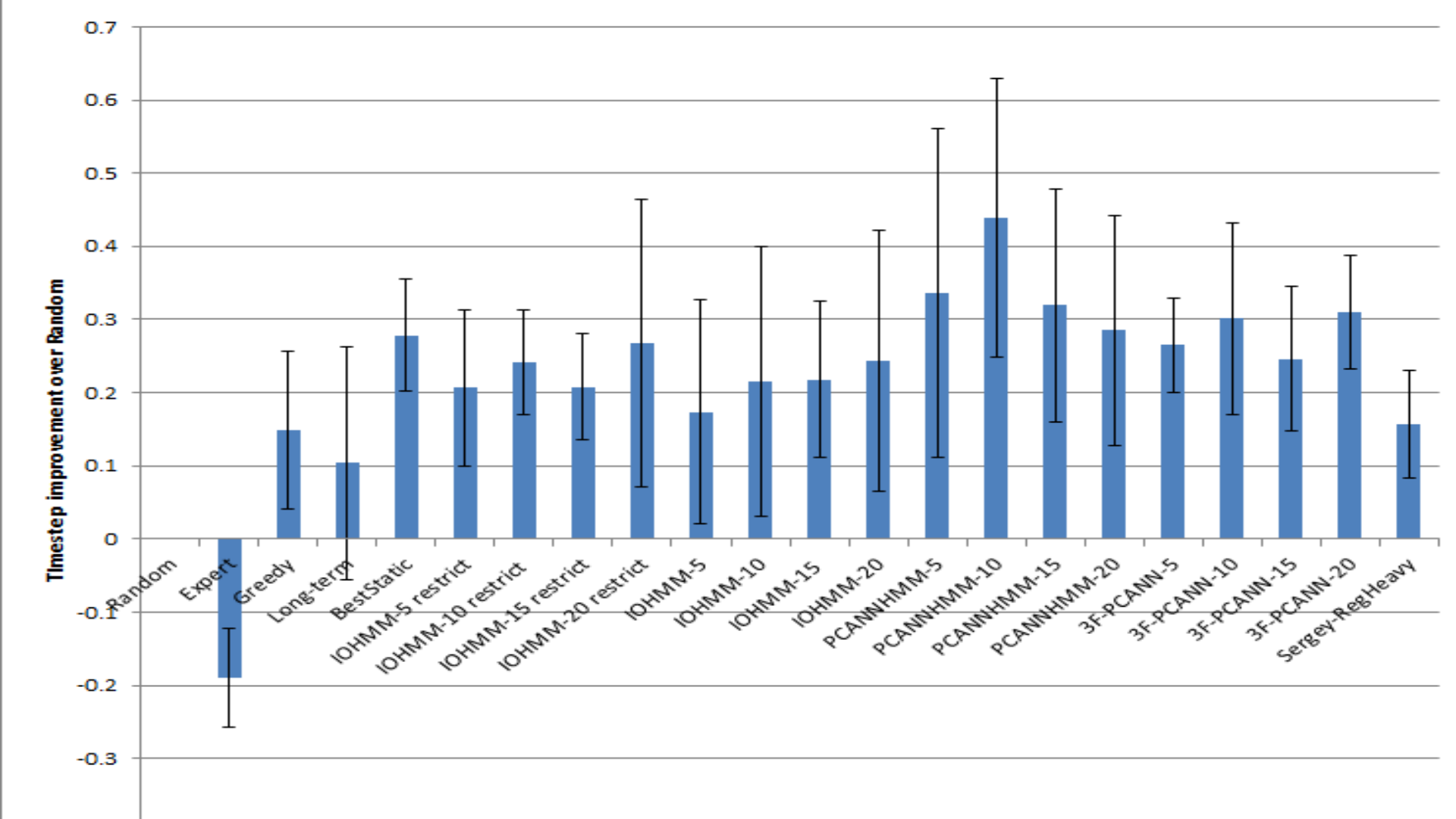
- Optimal hinting strategies
- Persistence and tenacity
- Long-term effects on domains
- Self-identification

The Zone Violation



Optimize for

- Long-term effects on learning
- Optimal assistive strategies
- Persistence and tenacity
- Self-identification

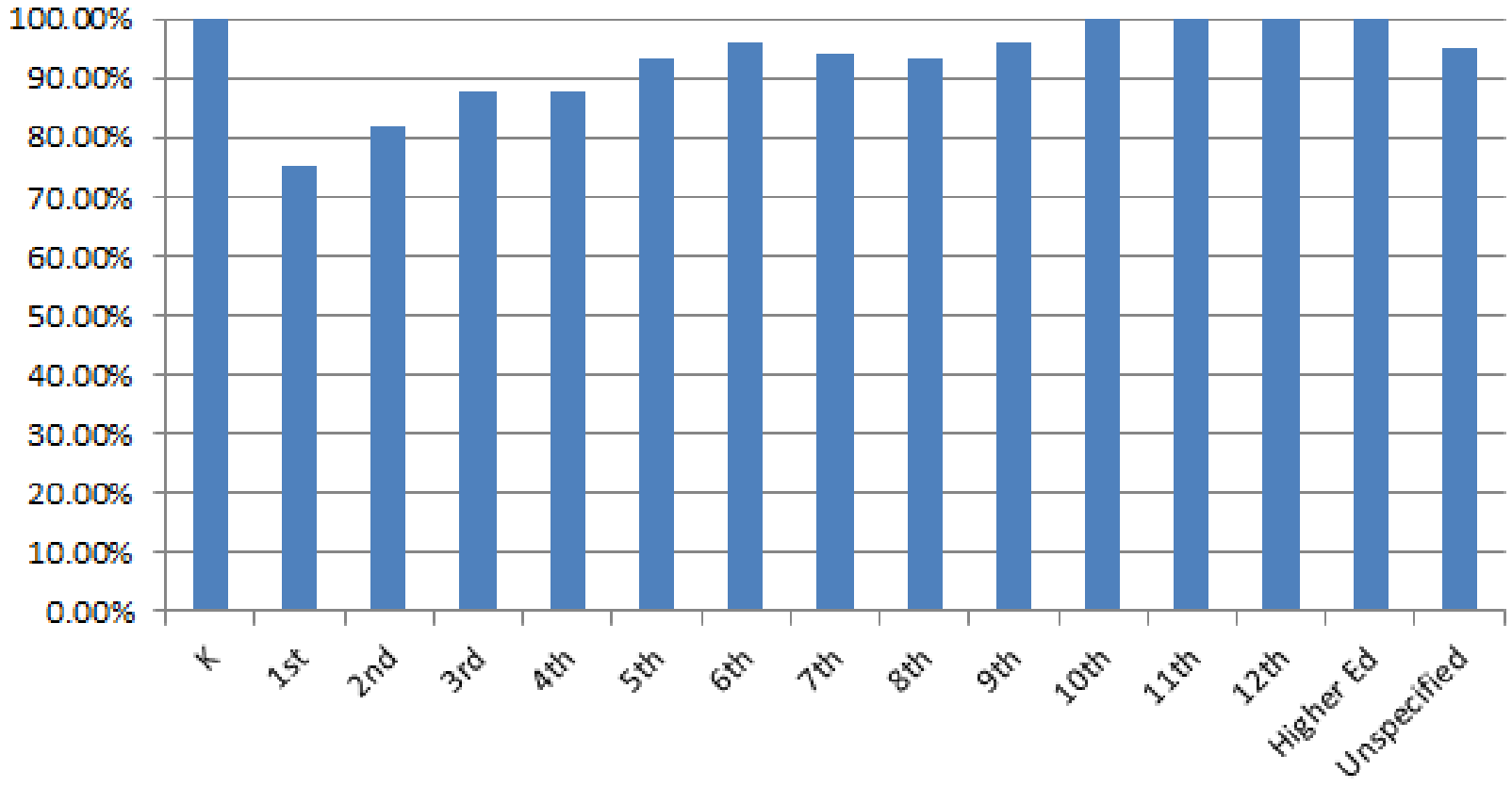

Timestep improvement over Random
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Random
Expert
Greedy
Long-term
BestStatic
IOHMM-5 restrict
IOHMM-10 restrict
IOHMM-15 restrict
IOHMM-20 restrict
IOHMM-5
IOHMM-10
IOHMM-15
IOHMM-20
PCANNHMM-5
PCANNHMM-10
PCANNHMM-15
PCANNHMM-20
3F-PCANN-5
3F-PCANN-10
3F-PCANN-15
3F-PCANN-20
Sergey-RegHeavy

Engaged Learning

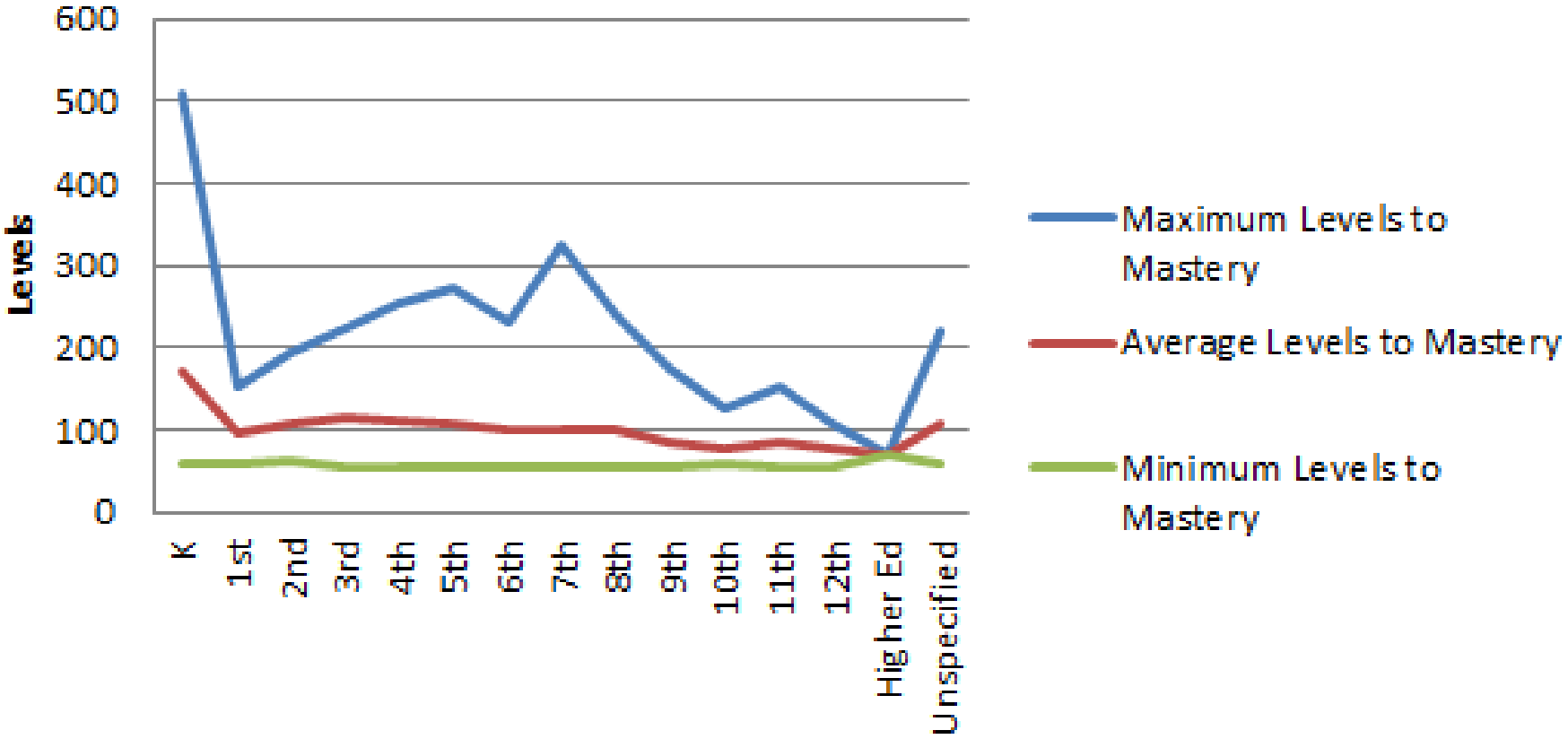
- Convert courseware into infinitely adaptable courseware
- Automatically adapt for each unique student
- Optimize for robust measures of engagement and mastery

Washington
Algebra Challenge

1.5 Hours of Play / Percent Acheived Mastery



Levels to Mastery



Effort to Mastery