Modes and Mechanisms of Game-like Interventions in Intelligent Tutoring Systems

Dovan Rai

Department of Computer Science

Worcester Polytechnic Institute

Joseph E. Beck
Ivon Arroyo

Charles Rich
Kristen Dicerbo

Educational Technology

Games

Intelligent
Tutoring Systems

Games

Rich experiences !

! Cognitive Overload

! Design Constraints

! Time Constraints

! Resource Constraints

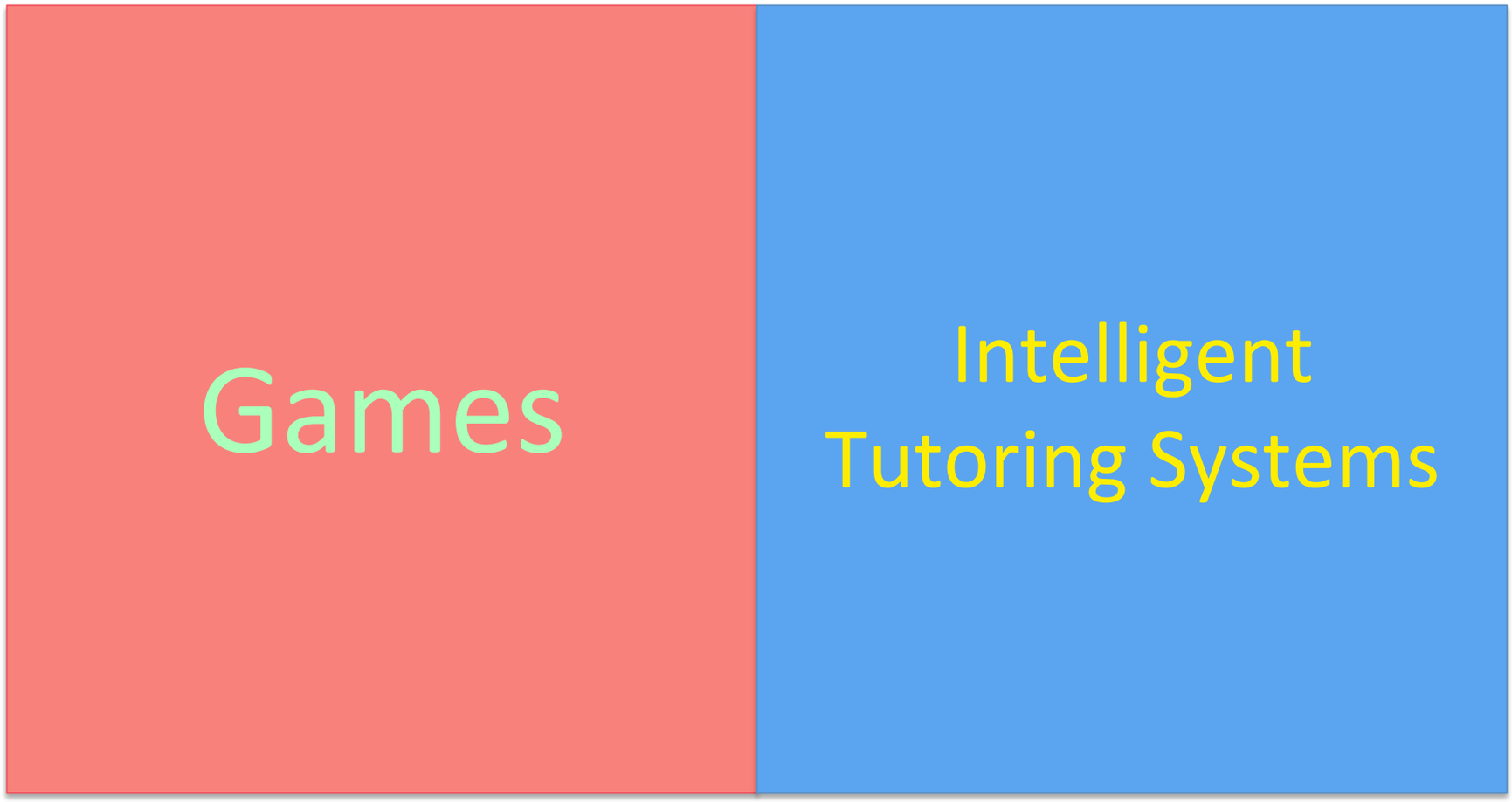
Learning gain !

Intelligent
Tutoring Systems

Can they hold students attention for prolonged time?

Can they provide adequate platform for
rich learning experiences?

Integrate Game and Tutors ?



Game-like Interventions *in* Intelligent Tutoring Systems

Deconstruction of Games

Game-elements

Game-like-elements

Games

Gamification

Mini-games

Intelligent Tutoring Systems

Game-like Interventions

Modes and Mechanisms of Game-like Interventions In Intelligent Tutoring Systems

Research Questions

1. What are different MODES of game-like interventions?

2. What are the MECHANISMS of learning outcomes in game-like interventions?

What are the different ways we can have game-like interventions in computer tutors?

games

Tutors

games

games

game-like interventions

COGNITIVE

Monkey's Revenge

game-like math tutor

METACOGNITIVE

Learning Dashboard

Gamification

Tutors

AFFECTIVE

Mosaic

Mini-games

EXPERIMENTS

Monkey's Revenge
game-like math tutor

1. Pilot study (N=58)

   Modified intervention

2. Pilot study (N=39)

3. RCT (N=297)

   Modified intervention

   Modified study design

4. RCT (N=252)

Learning Dashboard
Gamification

1. Pilot study (N=58)
2. RCT (N=39)

   improved intervention

   Modified study design

3. RCT (N=252)

   Improved intervention

Mosaic
Mini-games

RCT (N=186)

Monkey's Revenge

game-like math tutor

Math problems wrapped in a visual narrative

MONKEY'S REVENGE

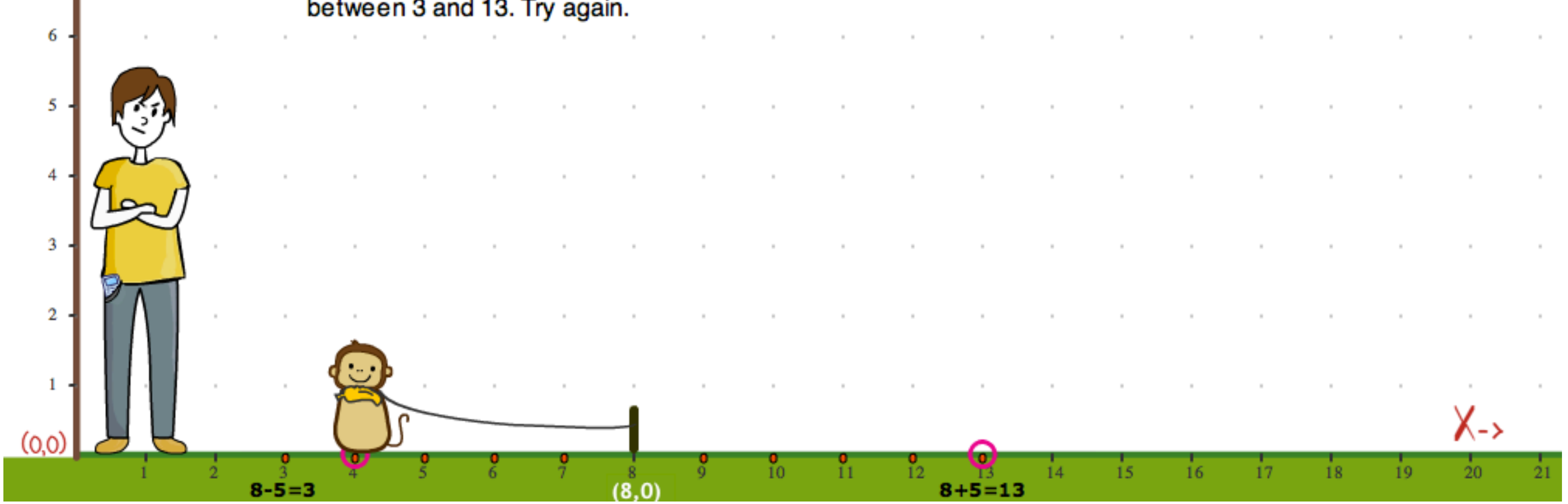
Sarah

Comment

He is tied to a stick at (8,0). If the length of the rope is 5 units, find the place where he cannot reach the banana?

(10,0) (13,0) (4,0) (2,0) SUBMIT Show Hint 1 of 3

Oops! Pepe can reach here. He can reach anywhere on the ground with x-coordinate between 3 and 13. Try again.
Sorry. Pepe can reach here. He can reach anywhere on ground with x-coordinate between 3 and 13. Try again.



Game Elements

Fantasy

Achievements

Narrative

Personalization

Levels

Collecting badges

Visual feedback

Quests

Resource Management

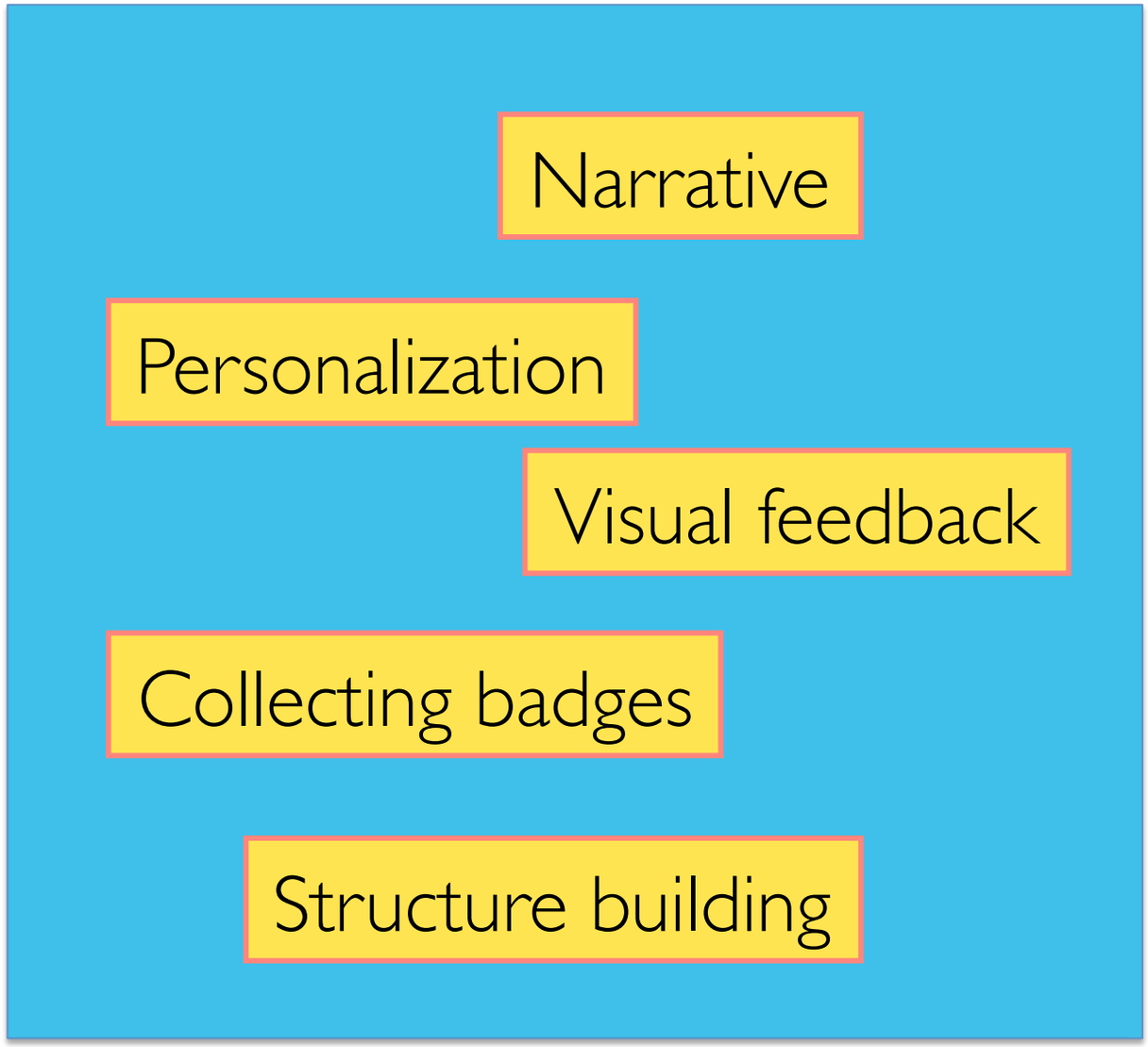
Competition

Tile laying

Structure building

Speed

Game-like Math Tutor



Experiments with Monkey's Revenge

1. Pilot study (N=58)

   Modified intervention

2. Pilot study (N=39)

3. RCT (N=297)

   Modified intervention

   Modified study design

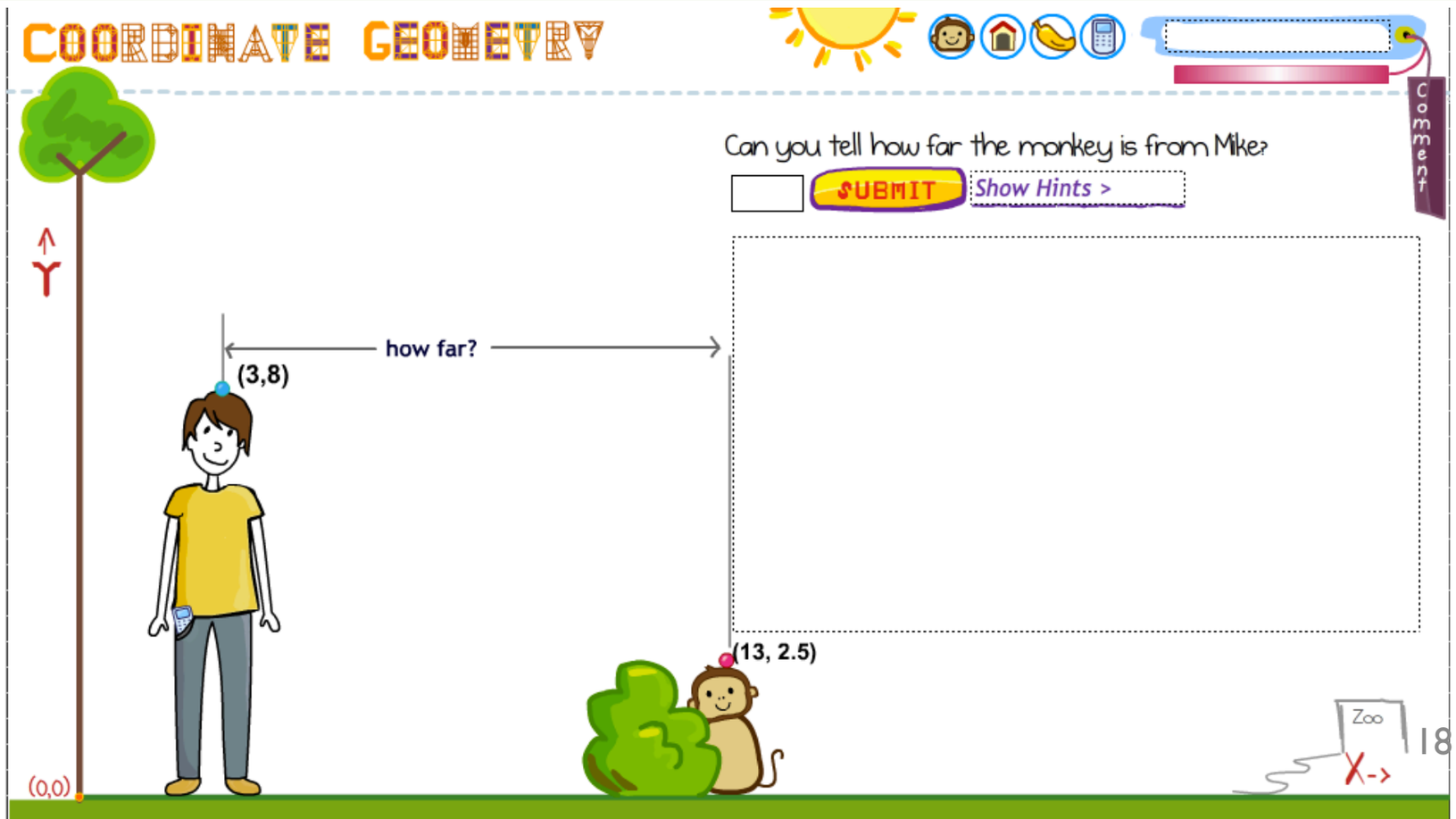
4. RCT (N=252)

EXPERIMENT DESIGN

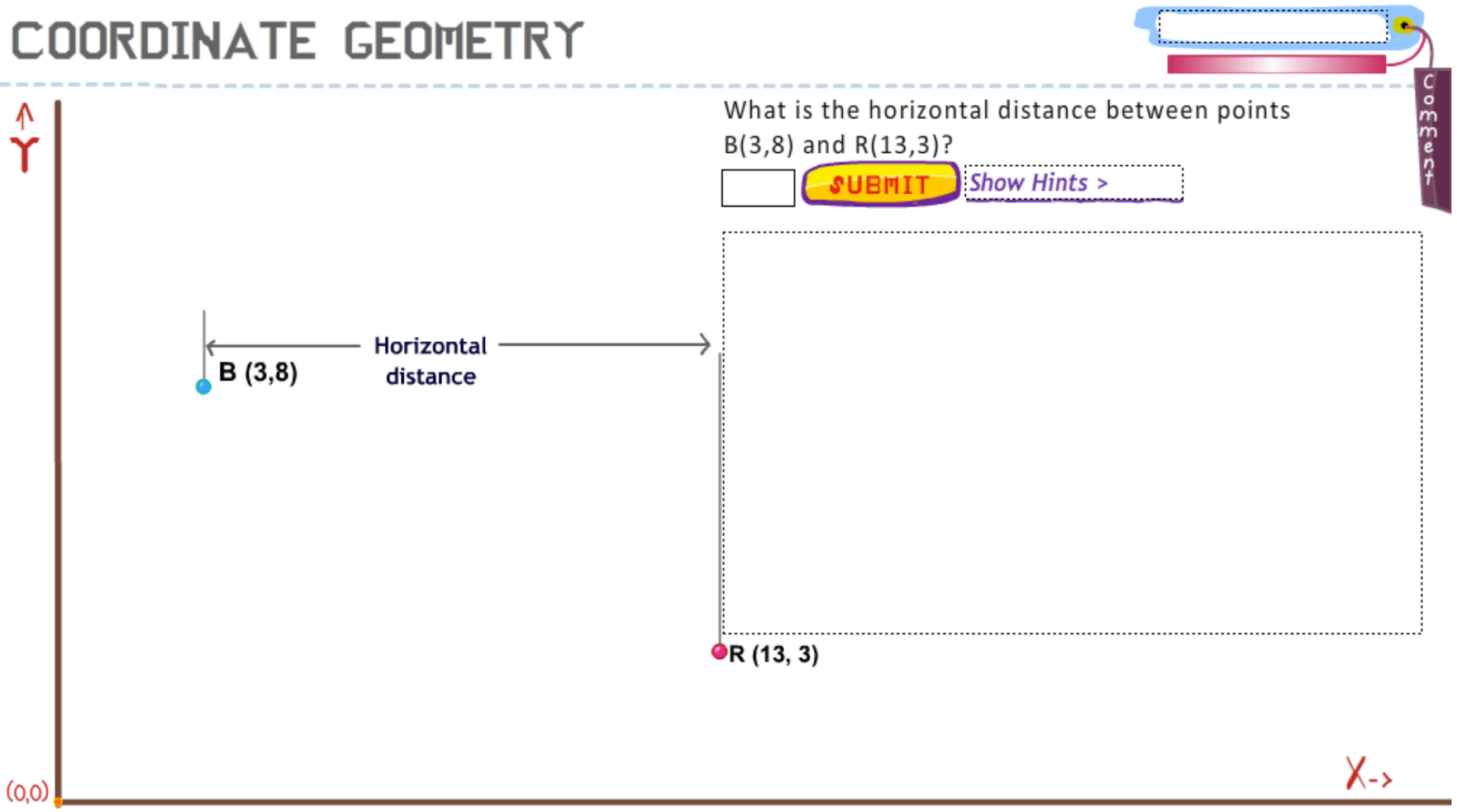
Tutor version	Visual feedback	Narrative	Other game-like elements
Monkey's Revenge	✔	✔	✔
without visual feedback	✘	✔	✔
without narrative	✔	✘	✔
Basic tutor	✘	✘	✘

Monkey's Revenge

Without narrative



Basic Tutor


COORDINATE GEOMETRY
What is the horizontal distance between points B(3,8) and R(13,3)?
SUBMIT
Show Hints >
Comment
Y
Horizontal distance
B (3,8)
R (13, 3)
(0,0)
X->
19

Monkey's revenge

Sarah

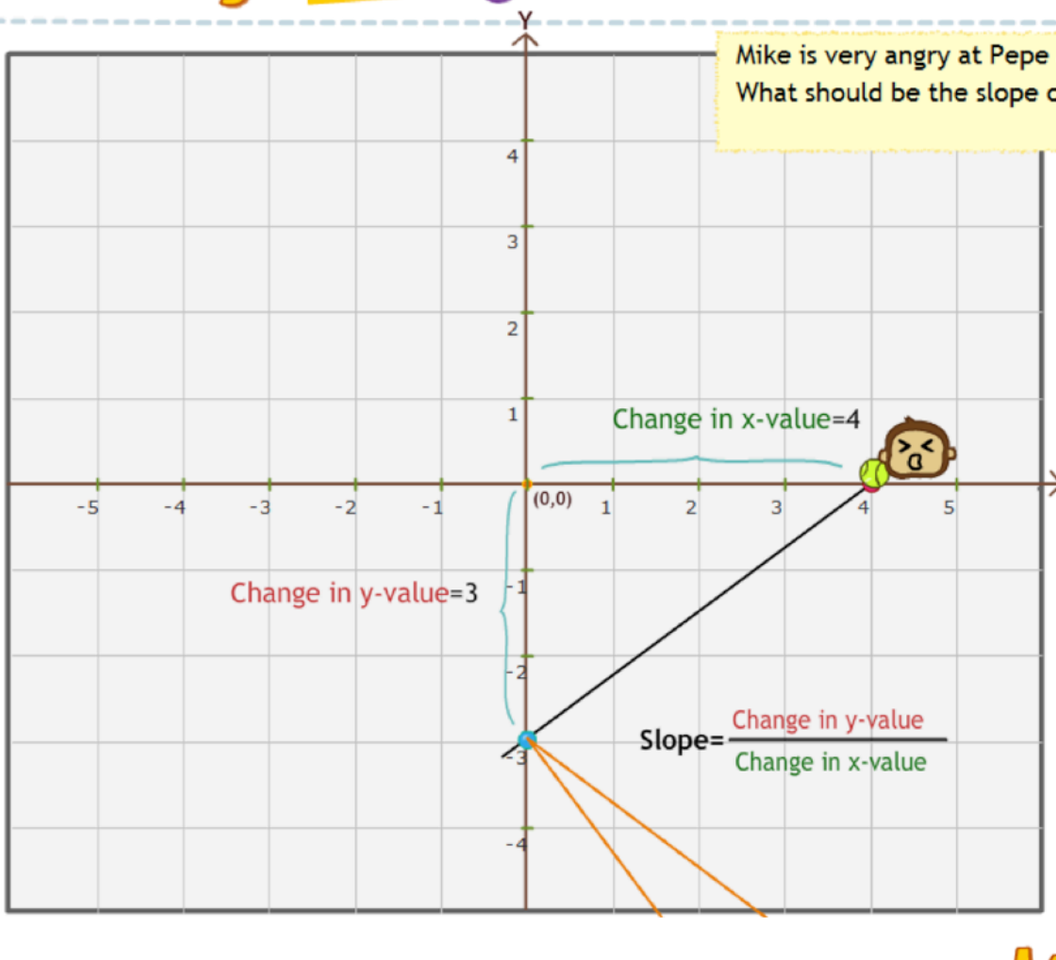
Mike is very angry at Pepe and wants to throw a ball at him.
What should be the slope of the path of the ball to hit Pepe?

3/4 -3/4 SUBMIT

4/3 -4/3 Show Hint 1 of 3 >

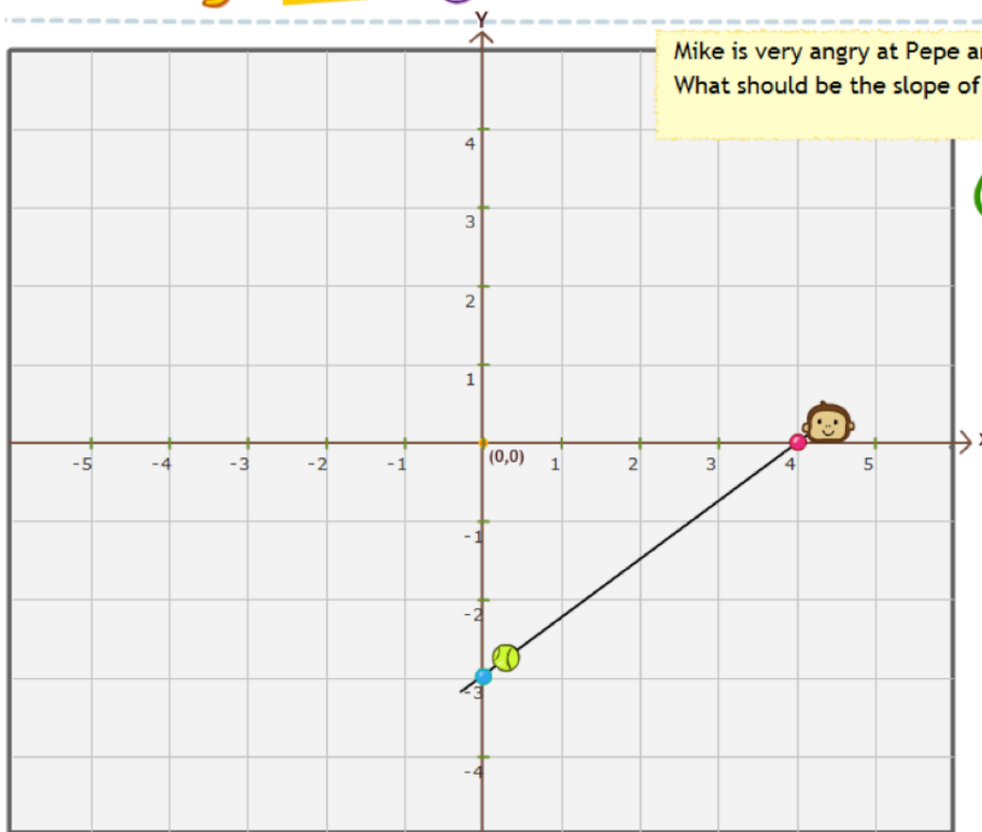
Right. You found the slope given two points.

NEXT PROBLEM >



Monkey's Revenge

Without Visual feedback



Hypothesis

Can game-like tutor

enhance student's enjoyment?
generate higher learning gain?

WITHOUT

creating cognitive overload

and taking too much time away from practice

Is it engaging? (Liking and satisfaction)

Is it effective? (learning gain)

Is it efficient? (time overload? cognitive overload?)

Is it engaging? (Liking and satisfaction)

Survey Responses across tutors (means and 95% CI)

Tutor version	Like tutor	Had fun	Tutor helped	Better
Monkey's Revenge	4.0±0.3	4.1±0.4	3.9±0.3	3.9±0.3
without visual feedback	3.9±0.4	3.9±0.4	3.6±0.4	3.7±0.4
without narrative	3.6±0.5	3.3±0.5	3.2±0.5	3.8±0.5
Basic tutor	3.0±0.5	3.0±0.5	3.1±0.5	3.4±0.5

Students liked the system.
They showed more liking of the tutor version with game-like elements.

Is it effective? (learning gain)

learning gain across tutors (means and 95% CI)

Tutor	Pretest percent correct	Learning gain
Monkey's Revenge	66%	10% ± 9%
without visual feedback	69%	5% ± 7%
without narrative	70%	7% ± 8%
Basic tutor	74%	3% ± 7%

Is it efficient? (cognitive overload?)

Student performance across tutors (means and 95% CI)

Tutor	Pretest percent correct	Problems correct in the tutor (max=27)
Monkey's Revenge	68%	20.3±1.1
without visual feedback	64%	19.8±2
without narrative	70%	18.6±1.2
Basic tutor	74%	18.5±1.5

We did not have a robust way to measure cognitive load. But at least, cognitive overload and distraction is not obstructing students in game-like version to perform well within the tutor.

Is it efficient? (time overload?)

Tutor	Total time (in minutes)	Non-tutor time (in minutes)
Monkey's Revenge	50	10
without visual feedback	47	13
without narrative	42	9
Basic tutor	56	5

Conclusions

Can game-like tutor

enhance student's enjoyment? YES
generate higher learning gain? no conclusion

without creating cognitive overload

and taking too much time away from practice
seems yes

Limitations and Future Work

No conclusive results on learning gains !

Possible reasons are:

- Intervention was brief
- Involved variety of skills

A lot of kids did not complete the post-test.

The large standard error suggests students were not taking the test seriously

Extend intervention for multiple sessions.

game-like interventions

COGNITIVE

Monkey's Revenge

game-like math tutor

METACOGNITIVE

Learning Dashboard

Gamification

Tutors

AFFECTIVE

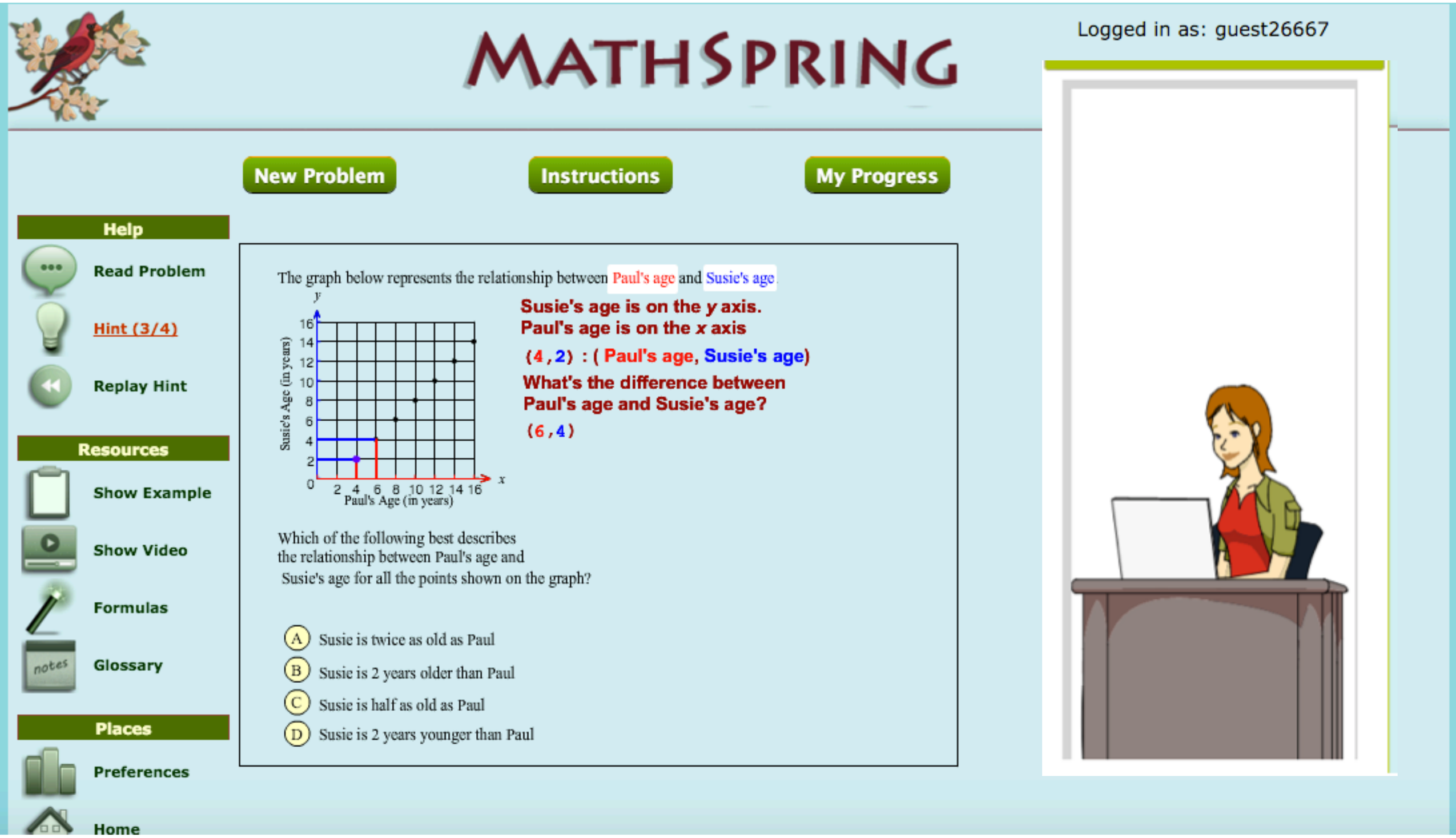
Mosaic

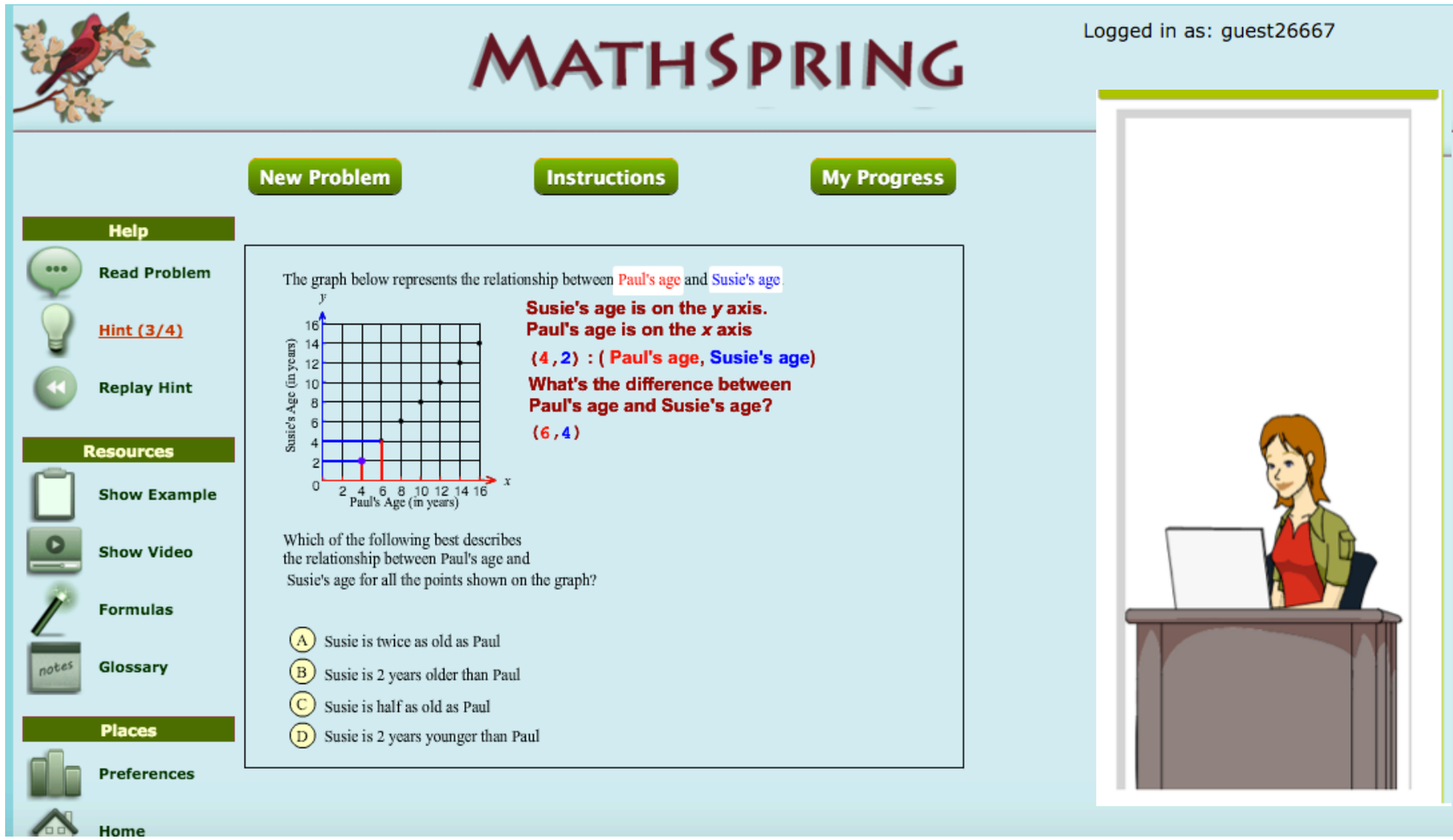
Mini-games

Learning Dashboard

gamification

MathSpring: Intelligent Tutoring System





Learning Dashboard

Math Tree

Student Progress Page (SPP)

Topic Details

MATHSPRING Dashboard

Damyan D | Log Out

Start Working | My Progress

Hi Damyan,

Welcome to MathSpring!

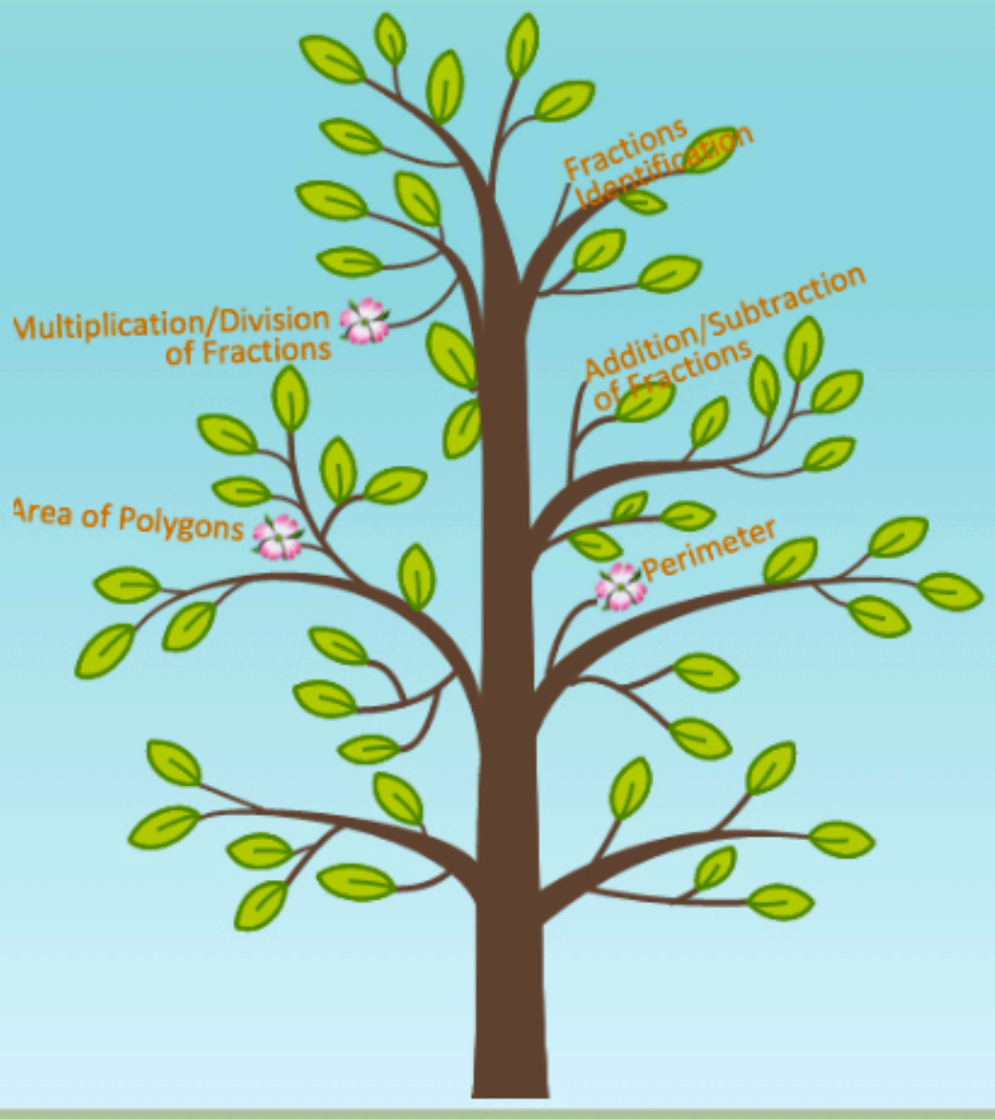
You are given this baby tree. It will grow as you practice math problems and learn. There are hints, examples and videos to help you learn to solve the problems.
Do you want to see how your tree may look like in future?

Show me the tree

Have a good time working on these math problems !

MATHSPRING Dashboard

Damyan D | Log Out



Start Working | My Progress

Hi Damyan,

Welcome back!
You had logged in 27 days ago. You have solved 37 problems so far. You have already mastered 3 topics. You also mastered 1 topic in that session.

You can see how you have progressed over days of practice.

Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6

Have a good time working on these math problems !

Student Progress Page (SPP)

MATHSPRING My Progress

« Go back to Tutor

Topic	Progress	Performance	Remarks	Actions
Fractions Identification		Mastery Level 38 Problems Done : 4/6 Learn More >	You got the last problem correct on first attempt. Keep up the good work and you can soon get the mastery. Comment >	Continue » « Review Challenge
Addition/Subtraction of Fractions		Mastery Level 10 Problems Done : 5/7 Learn More >	As you put more effort on solving the problems, the baby pepper plant grows to give pepper fruits. Comment >	Continue » « Review Challenge
Multiplication/Division of Fractions		Mastery Level 0 Problems Done : 0/7 Learn More >	Untried topic- Would you like to try this topic now? Comment >	Try this »
Perimeter		Mastery Level 59 Problems Done : 4/12 Learn More >	If you do not put effort on solving the problems, but rather keep guessing and giving up and not reading carefully, the plant wilts. Comment >	Continue » « Review Challenge

Student Progress Page (SPP)

MATHSPRING My Progress

« Go back to Tutor

EFFORT

MASTERY

Topic			Remarks	Actions
Fractions Identification		Mastery Level 38 Problems Done : 4/6 Learn More >	You got the last problem correct on first attempt. Keep up the good work and you can soon get the mastery. Comment >	Continue » « Review Challenge
Addition/Subtraction of Fractions		Mastery Level 10 Problems Done : 5/7 Learn More >	As you put more effort on solving the problems, the baby pepper plant grows to give pepper fruits. Comment >	Continue » « Review Challenge
Multiplication/Division of Fractions		Mastery Level 0 Problems Done : 0/7 Learn More >	Untried topic- Would you like to try this topic now? Comment >	Try this »
Perimeter		Mastery Level 59 Problems Done : 4/12 Learn More >	If you do not put effort on solving the problems, but rather keep guessing and giving up and not reading carefully, the plant wilts. Comment >	Continue » « Review Challenge

Pepper plants : representation of effort

Effort ➔ Pepper plant grows

No Effort ➔ Pepper plant wilts

Hypothesis

Providing meta-cognitive support through the SPP will generate cascading effects:

→ enhance students' affective state

→ which should increase student engagement and productive behaviors such as spending time on help, which should lead to higher learning

Experiments with Learning Dashboard (SPP)

1. Pilot study (N=58)
2. RCT (N=39)
3. RCT (N=252)

Experimental Groups

{When students show negative affect}

NO SPP	SPP	SPP	SPP
SPP button not present	SPP button	PROMPT SPP	FORCE SPP
(N = 49)	(N = 53)	(N = 52)	(N = 55)

Experiment and Results

Grade 7 (N = 209)
California

3 consecutive class sessions

PRETEST survey

Session 1

Session 2

Session 3

POSTTEST survey

MathSpring prompted students to self-report their affect

"How interested are you feeling right now?" Not at all interested (1) … somewhat interested (3) … extremely interested (5)

Does the SPP Impact Student Affect?

{on negative affect}

NO SPP	SPP	SPP	SPP
SPP button not present	SPP button	PROMPT SPP	FORCE SPP

Excitement	2.5	2.6	2.6	2.8
Interest	2.7	2.7	2.7	2.5

No Conclusion

Is SPP usage associated with Positive Affect?

{on negative affect}

NO SPP	SPP	SPP	SPP
SPP button not present	SPP button	PROMPT SPP	FORCE SPP

Is SPP usage associated with Positive Affect?

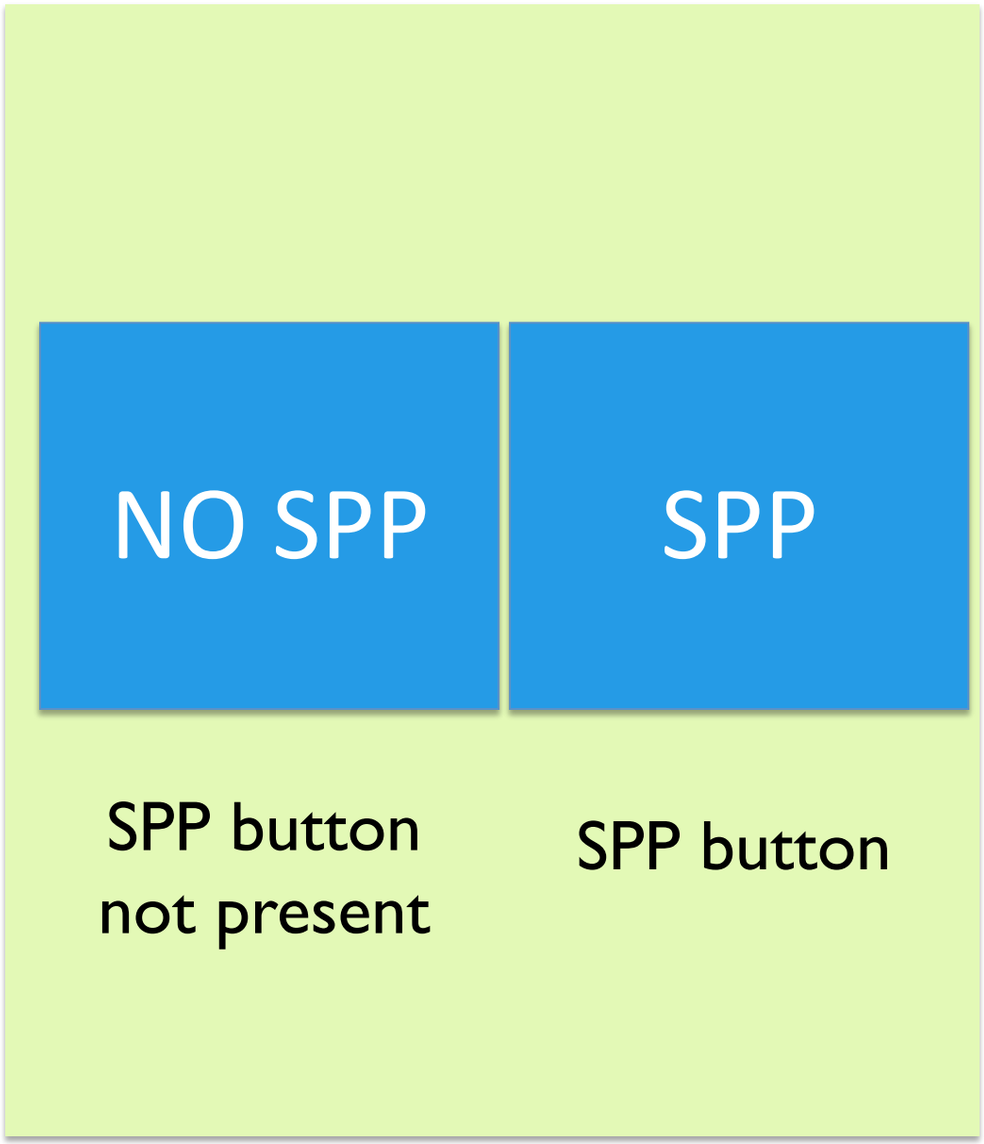
{on negative affect}

NO SPP	SPP	SPP	SPP
SPP button not present	SPP button	PROMPT SPP	FORCE SPP

! MathSpring encouraged SPP usage in two of the conditions (prompt and force) when low interest or low excitement was self reported.

{on negative affect}

NO SPP	SPP	SPP	SPP
SPP button not present	SPP button	PROMPT SPP	FORCE SPP



Interest was positively associated with SPP usage ($r = .24$, $p = .023$)
Excitement also was positively associated with SPP but this did not reach significance ($r = .13$, $p = .26$).

NO SPP	SPP
SPP button not present	SPP button

SPP usage → positive affect ?

or

positive affect → SPP usage ?

Interest was positively associated with SPP usage ($r = .24$, $p = .023$)

Excitement also was positively associated with SPP but this did not reach significance ($r = .13$, $p = .26$).

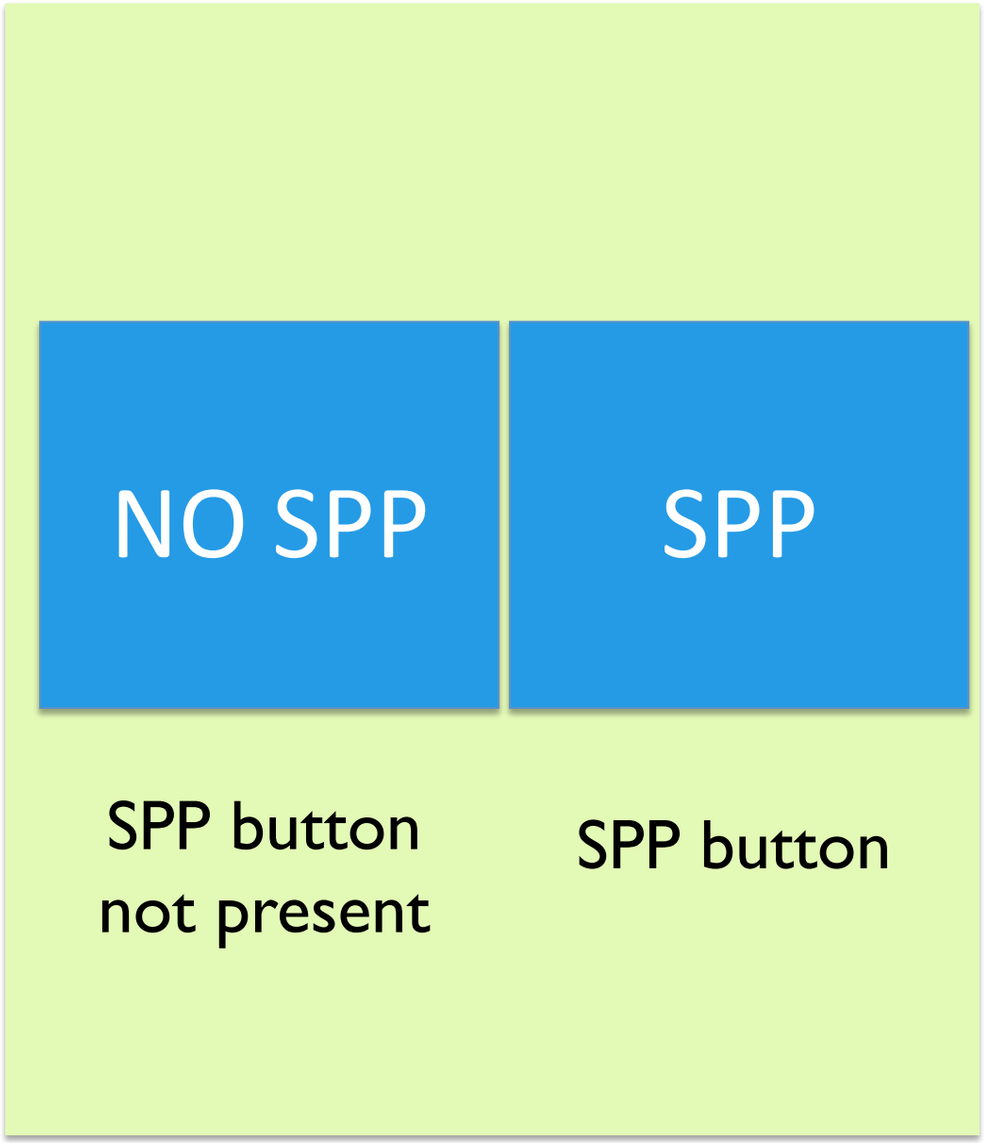
NO SPP	SPP
SPP button not present	SPP button

SPP usage → positive affect ?

or

positive affect → SPP usage ?

controlled for students' pre-existing affect as derived from the pre-affect survey



SPP usage → positive affect ?

or

positive affect → SPP usage ?

controlled for students' pre-existing affect as derived from the pre-affect survey

Interest was still significantly associated with SPP usage (r = .25, p = .036)

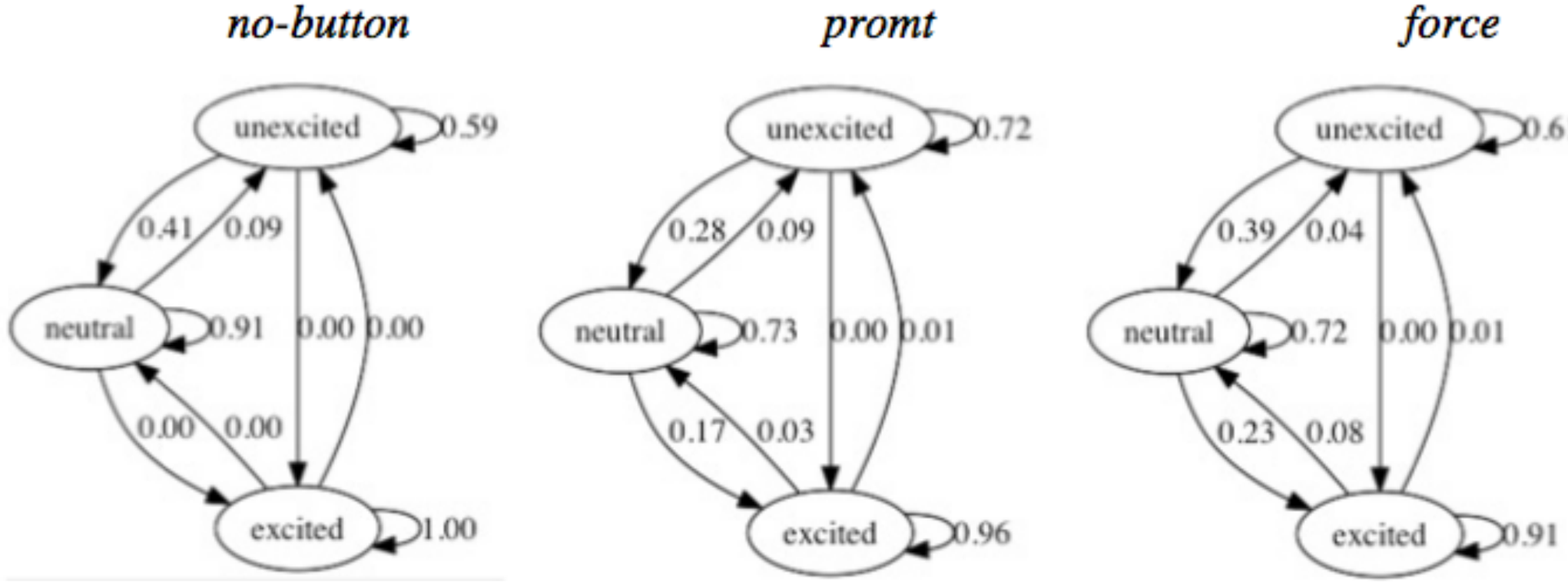
Excitement (r = .14, p = .3)

How do Conditions Impact Affective State Transitions?

(e.g., if they got "stuck" in the negative deactivating states)

How do Conditions Impact Affective State Transitions?

Models created by Wixon and Kasia



Visual representation of the high-level path models for excitement in the no-button, prompt and force conditions from left to right, respectively

SPP is affectively beneficial for students,

Promoting Excitement,

&

Decreasing the likelihood of paths

that lead to Boredom.

Limitations and Future Work

From personal observation of experimenters and teachers, students seem to enjoy SPP

We need better metrics to measure student affect and engagement

Make SPP more accurate and intuitive.

Longer study !

game-like interventions

COGNITIVE

Monkey's Revenge

game-like math tutor

METACOGNITIVE

Learning Dashboard

Gamification

Tutors

AFFECTIVE

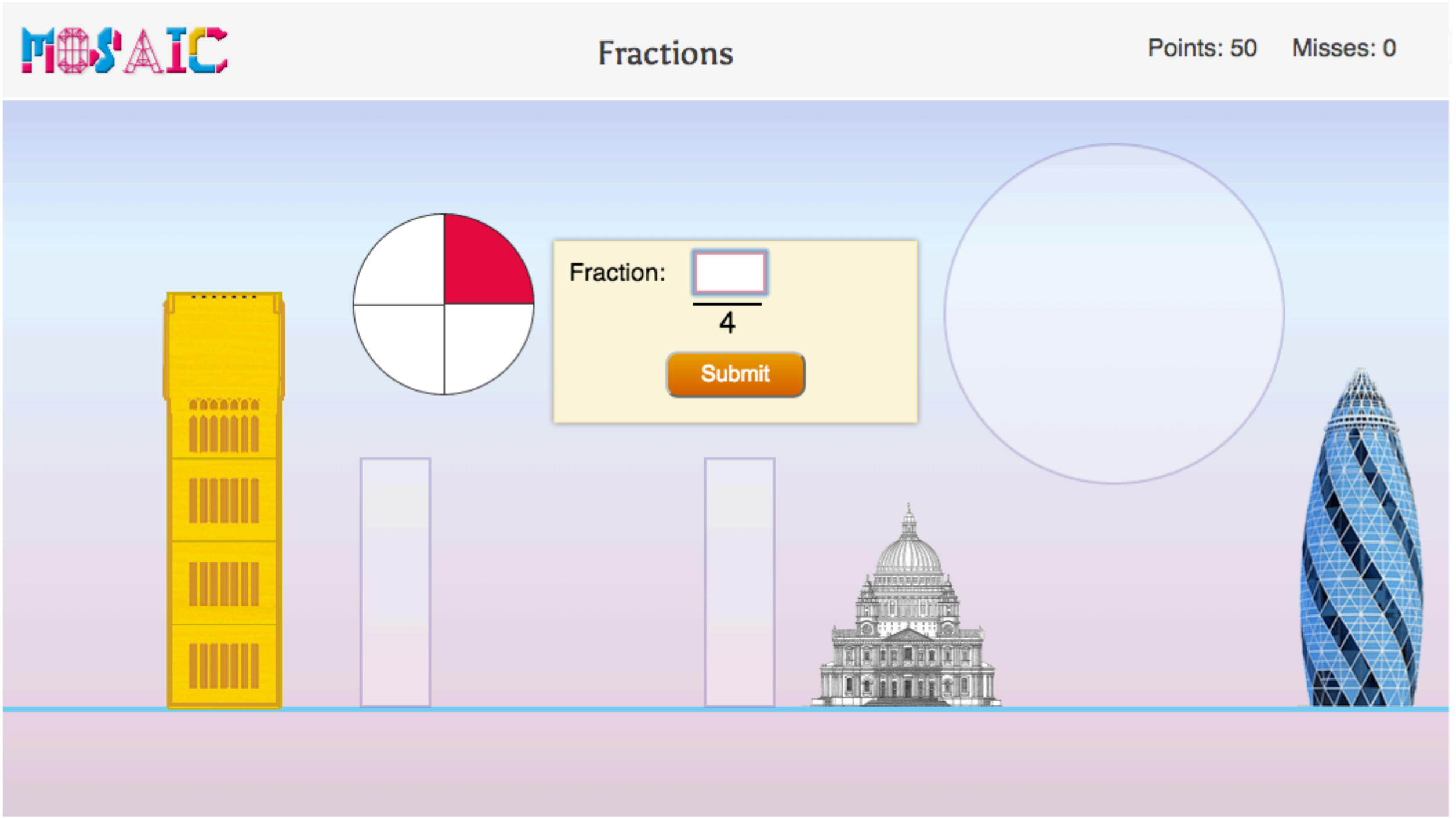
Mosaic

Mini-games

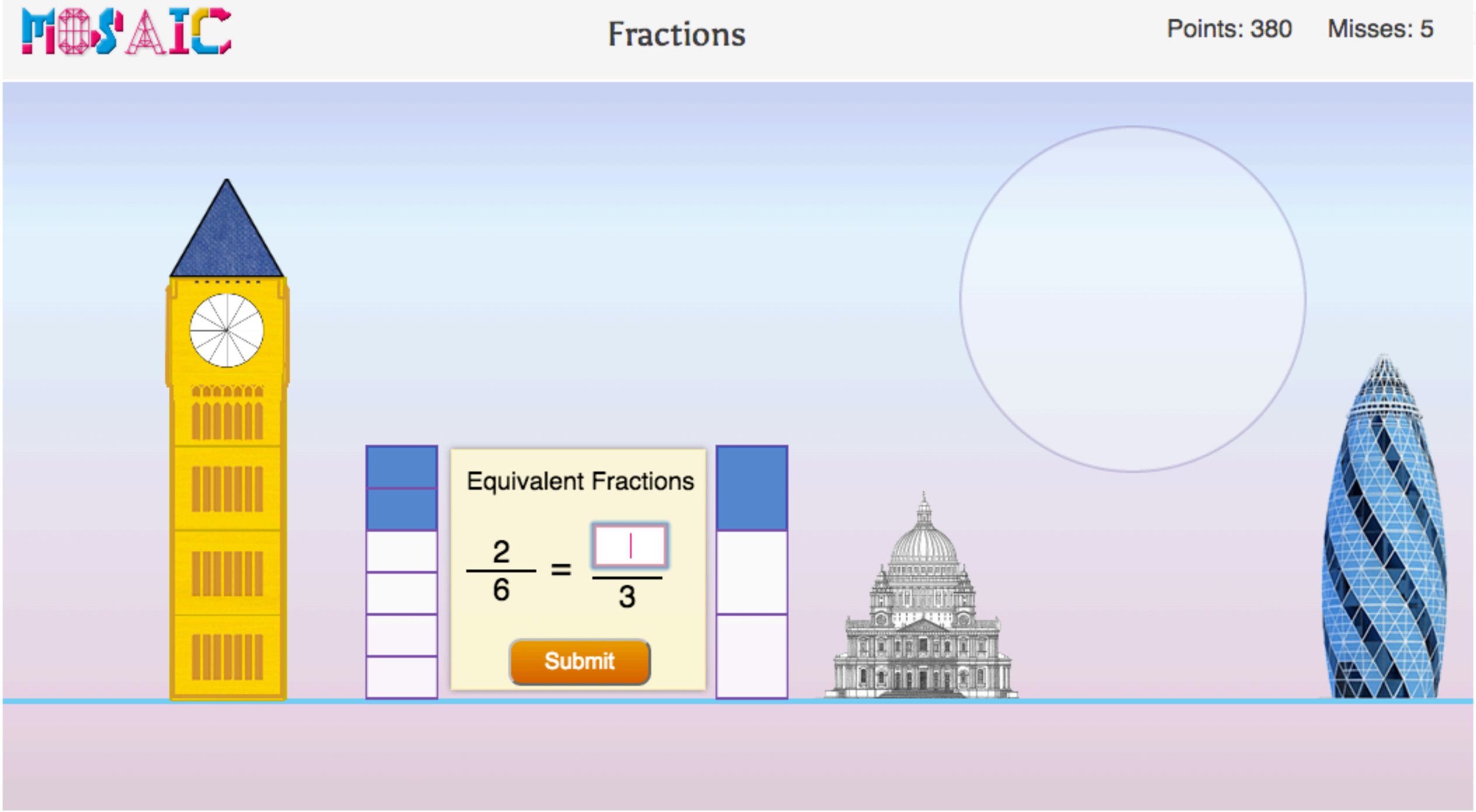
Mosaic

mini-games

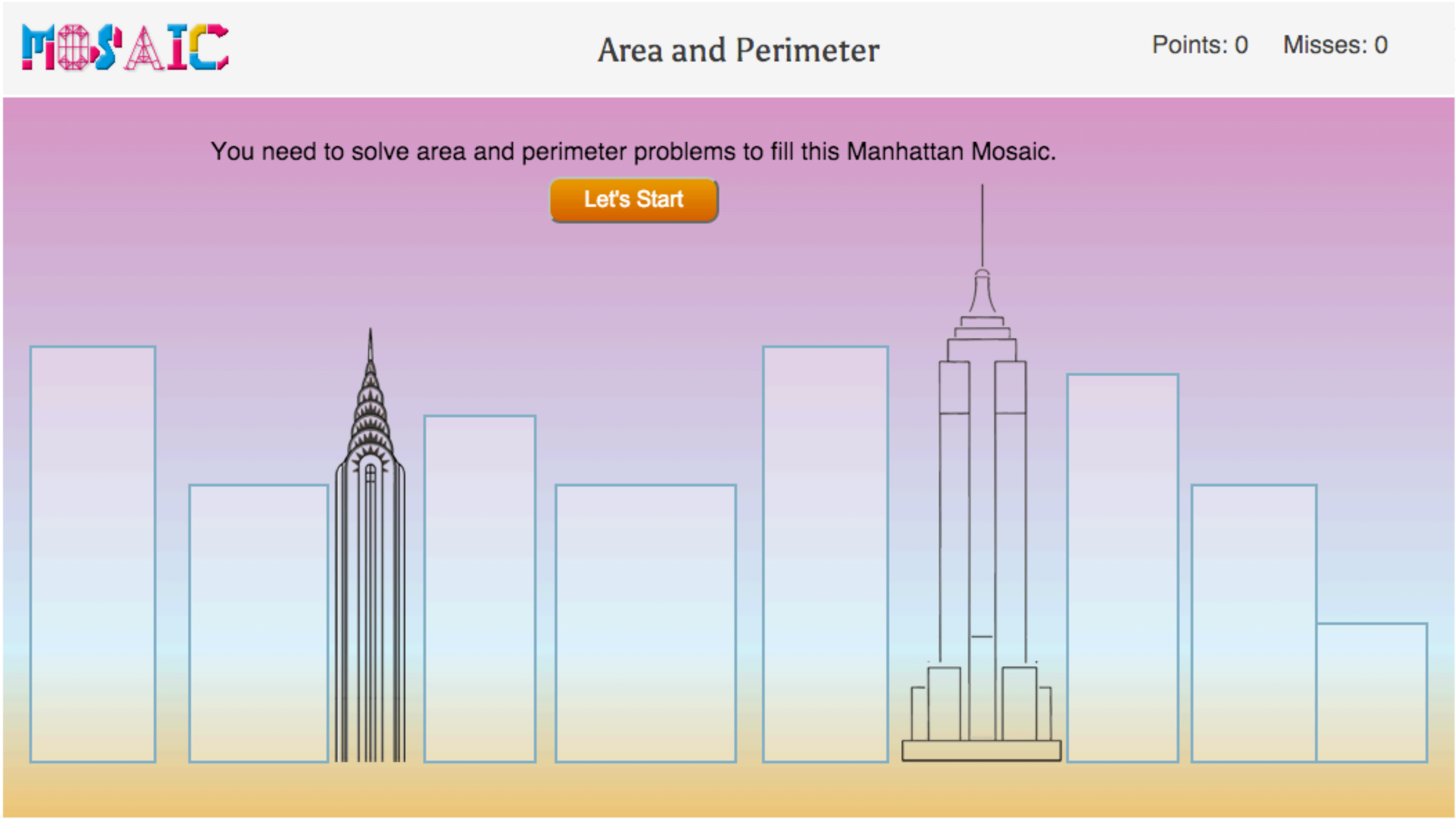
LONDON



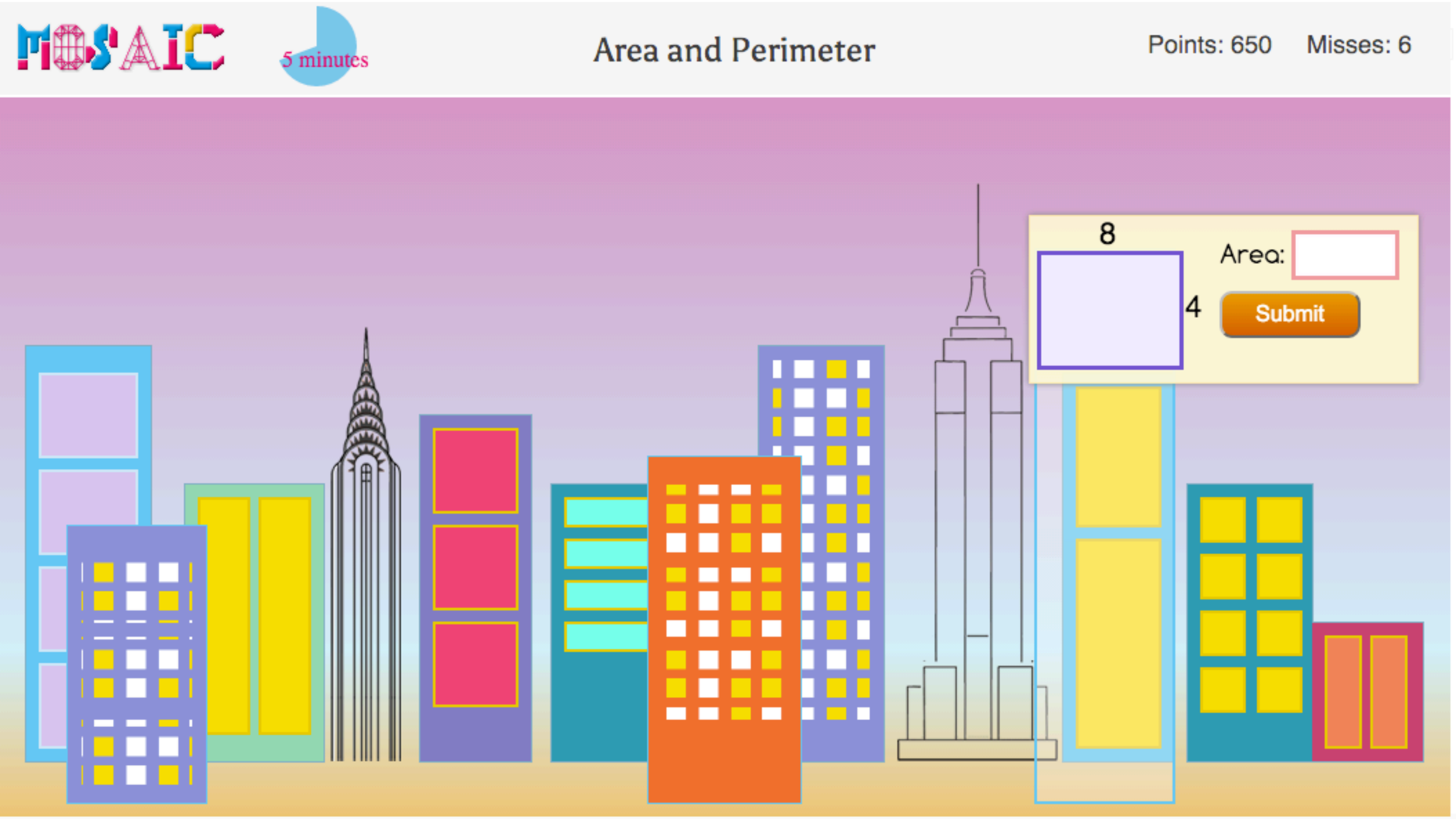
LONDON


MOSAIC
Fractions
Points: 380
Misses: 5
Equivalent Fractions
2/6 = ?/3
Submit

MANHATTAN


MOSAIC
Area and Perimeter
Points: 0
Misses: 0
You need to solve area and perimeter problems to fill this Manhattan Mosaic.
Let's Start

MANHATTAN


MOSAIC
5 minutes
Area and Perimeter
Points: 650
Misses: 6
8
4
Area:
Submit

Game as affective repair

After playing mini-games, students come back to tutor with better affect.

Experimental Groups

No-Mosaic	Prompt Mosaic	Force Mosaic
N=60	N=62	N=64

Experiment and Results

Grade 7 students (N = 186)

PRETEST survey

Session 1

POSTTEST survey

MathSpring prompted students to self-report their affect

"How interested are you feeling right now?" Not at all interested (1) … somewhat interested (3) … extremely interested (5)

Hypothesis

Do mini-games

enhance student affect ?
enhance student enjoyment and perception of tutor ?

Improve their engagement as a result of repaired affect?

Self-report on their experience in Mathspring; Students in different experimental groups

Group	Total participants	Participants with complete survey	Performed well (max 5)	Learned a Lot (max 5)	Enjoy using Mathspring (max 5)
No Mosaic	60	34	3.3 (1)	2.3 (1.1)	2.6 (1.2)
Prompt Mosaic	62	42	3.5 (1.2)	2.5 (1)	2.9 (1.2)
Force Mosaic	64	41	3.4 (1.4)	2.4 (1.2)	2.9 (1.3)

Self-report on their experience in Mathspring; Students who used Mosaic and who did not use Mosaic

Group	Total participants	Participants with complete survey	Performed well (max 5)	Learned a Lot (max 5)	Enjoy using Mathspring (max 5)
Did not use Mosaic	88	54	3.11	2.17	2.57
Used Mosaic	98	63	3.59	2.62	3.08
p-value			0.04*	0.03*	0.02*

Interest and Frustration averaged over participants who used and did not use Mosaic

Group	Interest (max 5)	Frustration (max 5)	Participants who skipped affect survey
Did not use Mosaic (N=88)	2.4 (N=55)	2.5 (N=66)	16 (18%)
Used Mosaic (N=98)	2.5 (N=65)	2.4 (N=60)	10 (10%)
p-value	0.4	0.08	

Limitations and Future Work

The whole experiment was only for a single class session.

The intervention was brief and affect sampling inadequate.

2. What are the MECHANISMS of learning outcomes in game-like interventions?

Causal Modeling is contested and not a widely used with educational technology community.

Therefore, we made a case study first to analyze and understand this approach.

We are using Causal modeling as an Exploratory tool rather than a Confirmatory one.

Causal Modeling Tool

TETRAD

http://www.phil.cmu.edu/tetrad/

Doug Selent's enhancement

https://sites.google.com/site/dougstetrad/tetrad

Causal modeling on Monkey’s Revenge

Causal modeling on Mathspring SPP

Causal modeling on Mosaic

Causal modeling on Mathspring SPP

We created variables from survey data

Samples:

MathLike : *Do you like your math class?*

IntePre: *In general, do you feel interested when solving math problems?*

AnxiPre*: Do you get anxious while solving math problems?*

DiffConcentration: *Do you have difficulty concentrating?*

enjoyMathSpring: *I enjoyed using the system.*

Student State variables

Student State	Description
SOF	Solved on first attempt without help
ATT	Answered after 1-2 incorrect attempts and self- corrected, without help.
SHINT	Answered with the use of some help, but not all, in at most 2 attempts.
GUESS	Answered after several attempts, more than 2 attempts
NOTR	Not enough time to read
GIVEUP	Enough time to read, but moved on before answering.

INTE: average value for “How Interested are you?”

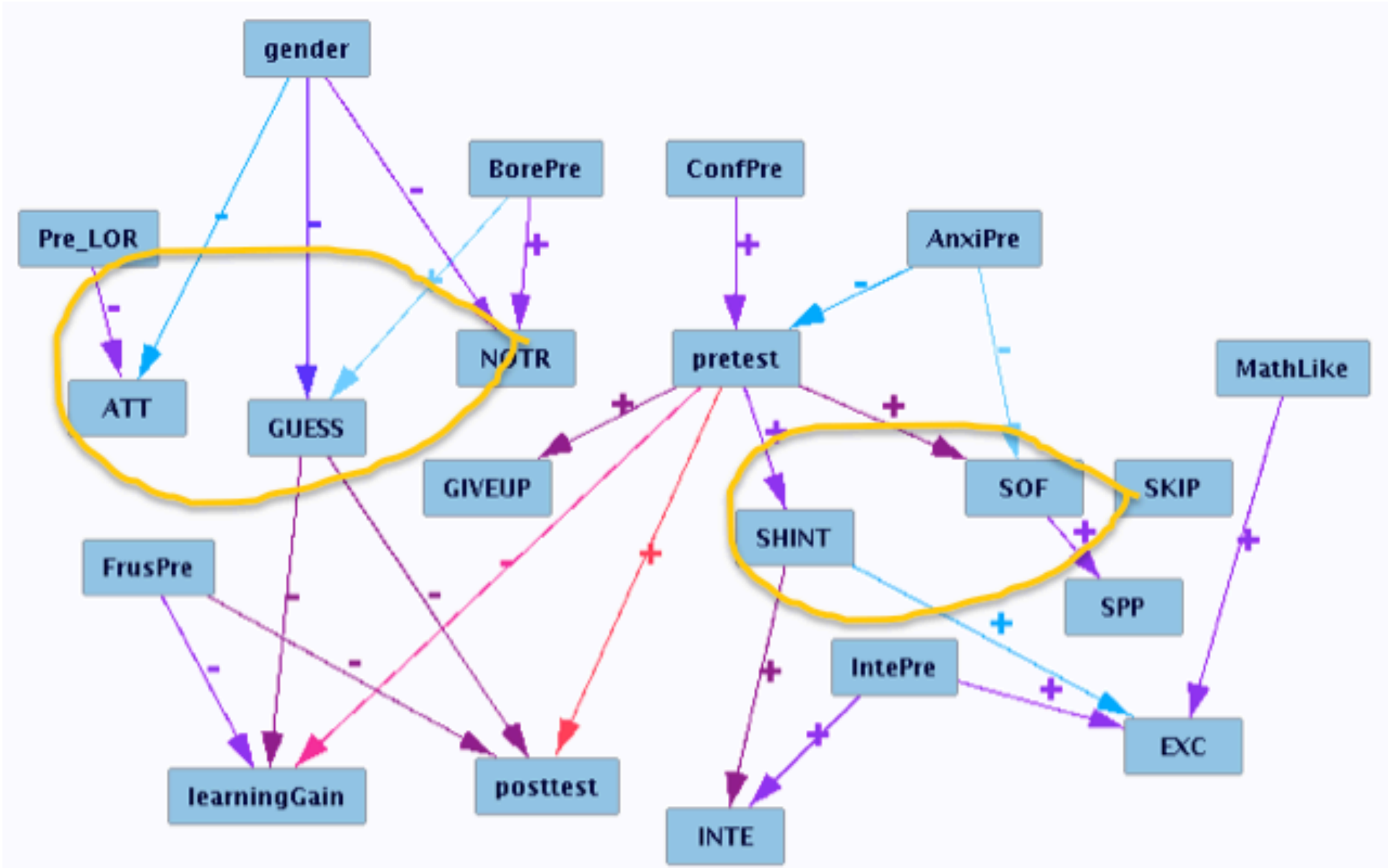
EXC: average value for “How excited are you?”

SPP: number of times SPP accessed by student

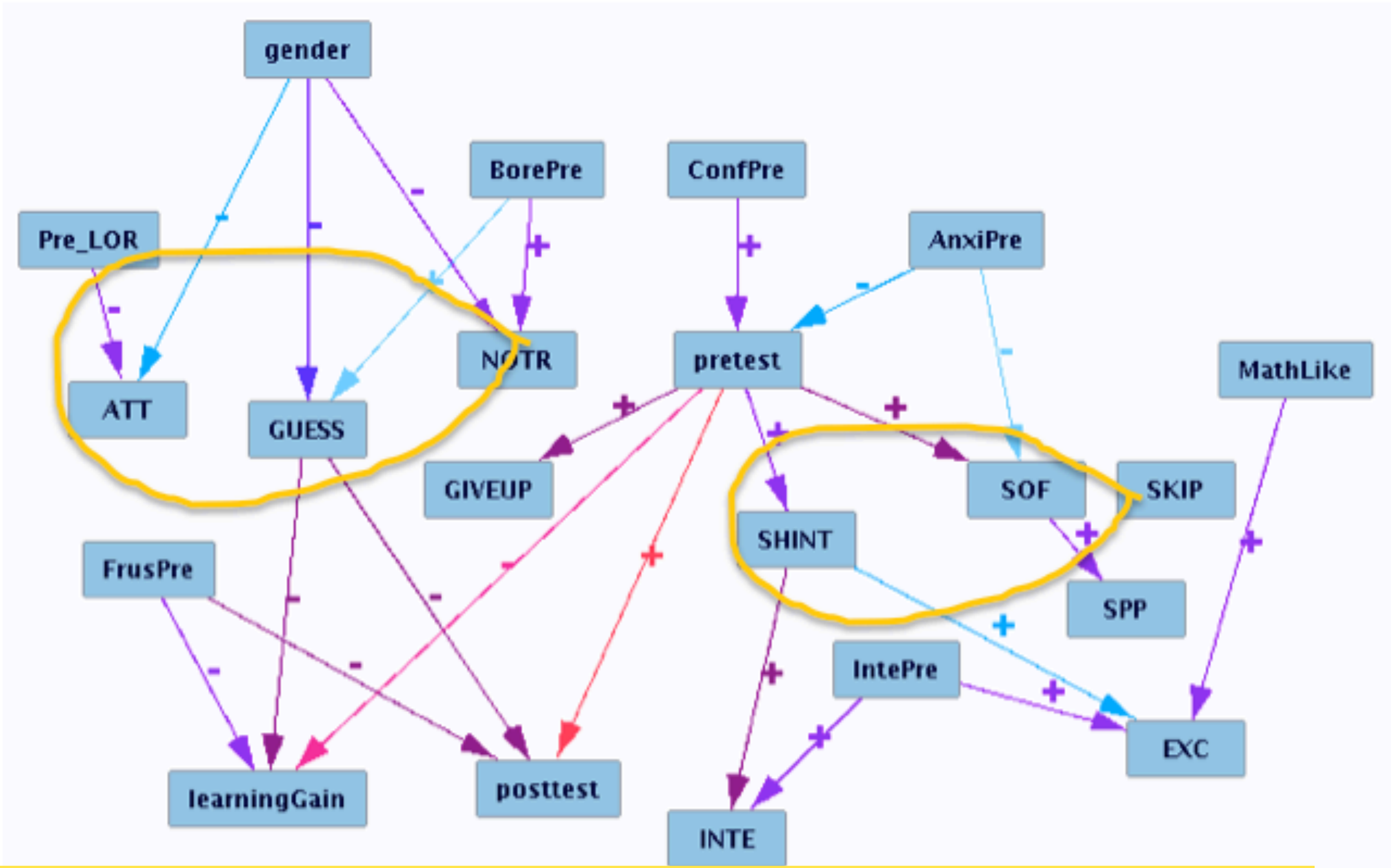
Clusters of variables

- Positive Learning vs. Negative learning behavior
- Performance Oriented vs. Enjoyment Oriented

Positive learning vs. negative learning behavior



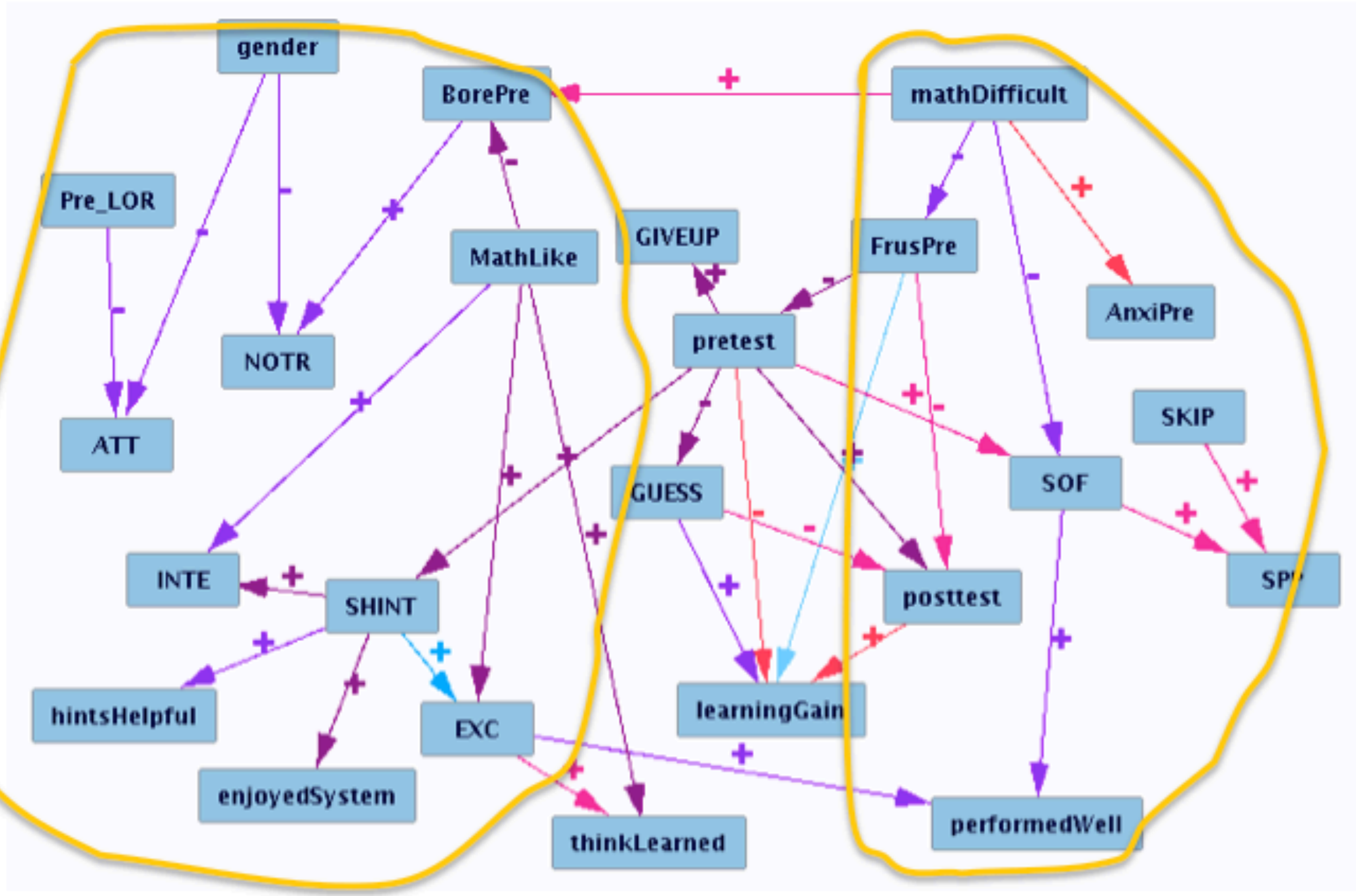
Positive learning vs. negative learning behavior

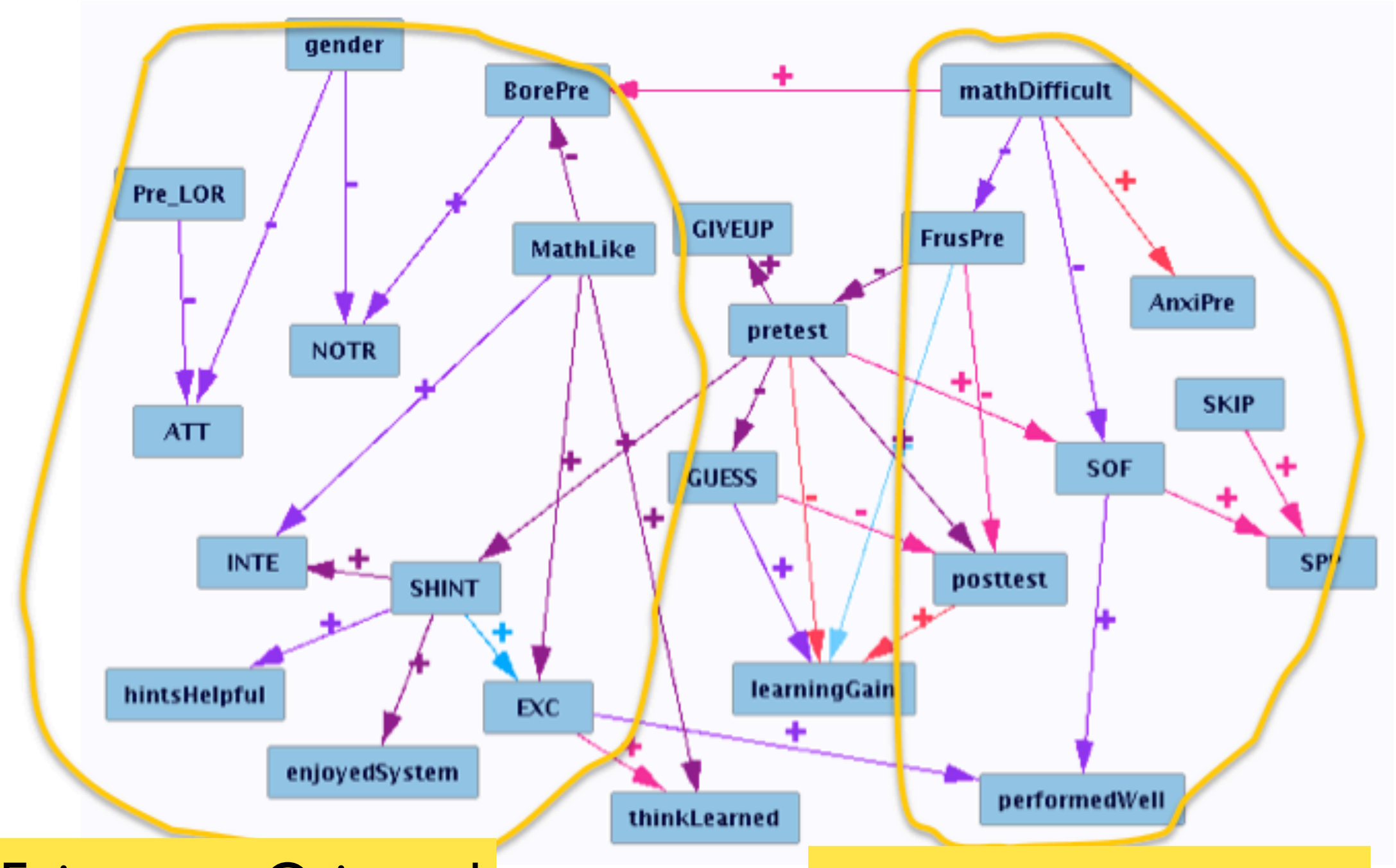


Assignment of these clusters are logical demarcation based on our domain knowledge rather than actual statistical distinction.

Positive Learning behavior	Effort (SOF, SHINT, ATT)	➔	Pepper plant grows
Negative Learning behavior	No Effort (NOTR, GUESS, SKIP, GIVEUP)	➔	Pepper plant wilts

Enjoyment Oriented vs. Performance Oriented





Enjoyment Oriented

students who used more tutor help **(SHINT)** reported enjoying the system more (enjoyedSystem), finding the tutor more helpful (tutorHelpful) and being more excited (EXC) and interested (INTE).

Performance Oriented

students who found math difficult (mathDifficult) solved less problems correctly in the first attempt **(SOF)**, reported higher anxiety (AnxiPre) and higher frustration (frusPre)

MATHSPRING My Progress

« Go back to Tutor

EFFORT

MASTERY

Topic			Remarks	Actions
Fractions Identification		Mastery Level 38 Problems Done : 4/6 Learn More >	You got the last problem correct on first attempt. Keep up the good work and you can soon get the mastery. Comment >	Continue » « Review Challenge
Addition/Subtraction of Fractions		Mastery Level 10 Problems Done : 5/7 Learn More >	As you put more effort on solving the problems, the baby pepper plant grows to give pepper fruits. Comment >	Continue » « Review Challenge
Multiplication/Division of Fractions		Mastery Level 0 Problems Done : 0/7 Learn More >	Untried topic- Would you like to try this topic now? Comment >	Try this »
Perimeter		Mastery Level 59 Problems Done : 4/12 Learn More >	If you do not put effort on solving the problems, but rather keep guessing and giving up and not reading carefully, the plant wilts. Comment >	Continue » « Review Challenge

SOF → Mastery

SHINT→ Effort

Special pepper plants as reward

Monster Pepper

SOF-SOF sequences
Exceptional Knowledge

Rainbow Pepper

SHINT-SOF sequences
Exceptional Help Usage

Modes and Mechanisms of Game-like Interventions In Intelligent Tutoring Systems

Conclusions

Major Limitations

- Lack of Usability studies
- Short Intervention duration
- Inadequate Study design (objective robust measures other than surveys)

Conclusions

Experimental data and classroom observations indicate that we are on the right path of creating optimal game-like interventions.

We need longer intervention duration and more robust study design to generate evidence that our interventions can enhance both enjoyment and learning gains.

What's the next optimal combination of tutors and games?

Intelligent Tutoring Systems

Students enter games with prior knowledge of the content.

Games as assessment tools

We can focus on creating rich learning experiences within an educational game while intelligent tutoring systems take care of providing robust learning

Thank You !

FULBRIGHT

ASSISTments
A Free Public Service of Worcester Polytechnic Institute

MATHSPRING

UMassAmherst

WORCESTER PUBLIC SCHOOLS
WORCESTER MASSACHUSETTS

WORCESTER POLYTECHNIC INSTITUTE 1865 WPI