The Challenge

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

Knowledge, Expert Principles
Student Instruction
Learners
Outcomes
Engaged Mastery

- People
- Engagement
- Expertise, Knowledge
- Discoveries, Education
Game developed experts

Prior knowledge of biochemistry

- None
- High school / Basic
- One undergraduate course
- Majored in biology or similar
- PhD in chemistry or organic chemistry
- PhD in biochemistry 30 years ago
- Professionally involved
Data-driven Game Evolution

refinement
Optimize for Engagement and Mastery
Importance of Early Math

Interest in STEM

Elementary School  Middle School  Time in School
Games for Massive Data-gathering to Optimize Learning Pathways
Secondary Award Effect

% of players

Time
Secondary Awards Considered Harmful

% of players

Time
Extrinsic Motivation: short term effect
Long term engagement: Self-identification
Create an exam

Game designer levels
Look here - it might be important!
Specialized Pathways to Mastery
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:

6, 7, 8

2

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

6, 8, 10, 12, ?

2

2

2

2

2

6, 8, 10, 12, 14

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

The final number in the pattern is 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:

<table>
<thead>
<tr>
<th>Figure</th>
<th># of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

Number of squares added each time: [2]

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)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

Rule:

b)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

Rule:

c)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>

Rule:

d)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Rule:

e)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Rule:

f)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
</tr>
</tbody>
</table>

Rule:
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:

   1   2   3   4   5   6

a)   

b)   

c)   

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

   Figure 1

   Figure 2

   Figure 3

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Line Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

   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

<table>
<thead>
<tr>
<th>Figure</th>
<th>Number of Triangles</th>
<th>Number of Line Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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:
   
   \[ 2 \times \text{Figure Number} \]

   Rule for the total number of blocks:
   
   \[ 2 \times \text{Figure Number} + 1 \]

   **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:

2. Draw or build a sequence of figures that might go with the following tables.
1. Write the value of each digit. Then complete the sentence.
   a) 3 7
   b) 4 7
   c) 5 4 7

   ______ is greater than ______
   ______ 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
   b) 360
   c) 852
   d) 136
   a) 465
   b) 260
   c) 858
   d) 126
   475
   465

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
   b) 629
   c) 576
   d) 432
   a) 597
   b) 654
   c) 603
   d) 431
   597
   654

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
   g) 354 or 358
   h) 296 or 290
   111
   625
   867
   480
   219
same # of digits?  NO  greater # of digits?  NO  report “less”

first digit same?  NO  first digit greater?  NO  report “less”

second digit same?  NO  second digit greater?  NO  report “less”

...
same # of digits? NO
first digit same? NO
second digit same? NO
... report “less”

NO
first digit greater? NO
d second digit greater? NO
report “less”

YES
report “greater”

YES
report “greater”

YES
report “greater”
same # of digits? NO

greater # of digits? NO
report “less”

first digit same? NO
first digit greater? NO
report “less”

second digit same? NO
second digit greater? NO
report “less”

...
same # of digits?

first digit same?

second digit same?

first digit greater?

second digit greater?
same # of digits? → NO → greater # of digits? → NO → report “less”

first digit same? → NO → first digit greater? → NO → report “less”

second digit same? → NO → second digit greater? → NO → report “less”

first digit same? → YES → report “greater”

second digit same? → YES → report “greater”

second digit same? → YES → report “greater”

...
same # of digits?

NO  greater # of digits?

NO  report “less”

NO  greater # of digits?

YES  report “greater”

YES  report “greater”

NO  report “less”

NO  report “less”

YES  report “greater”

YES  report “greater”

YES  report “greater”

NO  report “less”

NO  report “less”

NO  report “less”

NO  report “less”

NO  report “less”

...
同一数量的数字？

- 是
- 否

- 数字数量较多？
  - 是
    - 报告“更大”
  - 否
    - 报告“更小”

- 第一位数字相同？
  - 是
    - 报告“更大”
  - 否
    - 第一位数字较大？
      - 是
        - 报告“更小”
      - 否
        - 第二位数字相同？
          - 是
            - 报告“更大”
          - 否
            - 第二位数字较大？
              - 是
                - 报告“更大”
              - 否
                - 报告“更小”
Compare 313 to 324.
Compare 313 to 324.
What can we do with traces?

• Rank their difficulty

• Analyze and compare progressions

• Synthesize new progressions
Fraction Addition and Subtraction

Integer Addition
<table>
<thead>
<tr>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addition: Standard</td>
</tr>
<tr>
<td>Addition: Counting On</td>
</tr>
<tr>
<td>Division: Repeated Subtraction Full</td>
</tr>
<tr>
<td>Division: Repeated Subtraction Remainder Only</td>
</tr>
<tr>
<td>Fraction Division</td>
</tr>
<tr>
<td>Fraction Multiplication</td>
</tr>
<tr>
<td>Fraction Reciprocal</td>
</tr>
<tr>
<td>Fraction Reduction: Successive Division</td>
</tr>
<tr>
<td>GCF: Euclid’s Algorithm</td>
</tr>
<tr>
<td>GCF: Successive Division</td>
</tr>
<tr>
<td>GCF: Simultaneous Division</td>
</tr>
<tr>
<td>Matrix Addition</td>
</tr>
<tr>
<td>Matrix Subtraction</td>
</tr>
<tr>
<td>Matrix Scalar Multiplication</td>
</tr>
<tr>
<td>Pattern Continuation: Addition</td>
</tr>
<tr>
<td>Pattern Continuation: Subtraction</td>
</tr>
<tr>
<td>Pattern Continuation: Explicit Addition</td>
</tr>
<tr>
<td>Pattern Continuation: Explicit Subtraction</td>
</tr>
<tr>
<td>Prime Factorization</td>
</tr>
<tr>
<td>Subtraction: Counting Back</td>
</tr>
</tbody>
</table>
Conceptual Problems

• Algebra
• Geometry proofs
• Solving unknown problems
Complexity Grows Exponentially
Personalized Algebra
In-vivo courseware adaptation
Mastery

Engagement

Interactive Game Learning

Formative Assessment

Optimal 10-minute interventions

Teacher Development
Reinforcement Learning

Goal: Maximize student’s learning & engagement
Transfer

1-0

1-1a

1-2

1-3

1-4

1-5

2-0

3-0

Transfer
# Scaffolding RL experiments

- **Dwell Time (Time on Task)**

<table>
<thead>
<tr>
<th>A</th>
<th>A</th>
<th>A</th>
<th>B</th>
<th>B</th>
<th>B</th>
<th>AB</th>
<th>AB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>AB</td>
<td>C</td>
<td>ABC</td>
<td>D</td>
<td>ABCD</td>
<td></td>
</tr>
</tbody>
</table>

- **Concept layering**

  ... ABC D AD BD CD ABD ACD ABCD

  ... ABC D ABCD E ABCDE

- **Concept Ordering**

<table>
<thead>
<tr>
<th>B</th>
<th>BC</th>
<th>A</th>
<th>ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>C</td>
<td>ABC</td>
<td>F</td>
</tr>
</tbody>
</table>
Key RL experiments

• Optimal hinting strategies
• Persistence and tenacity
• Long-term effects on domains
• Self-identification
The Zone Violation

0-star

- Medium/poor performance (85%)
- Strong performance (15%)

5-star

- everyone does poorly

1-star

0-star (2x)
Optimize for

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