



# Intelligent Tutoring System: The importance of the Inner Loop

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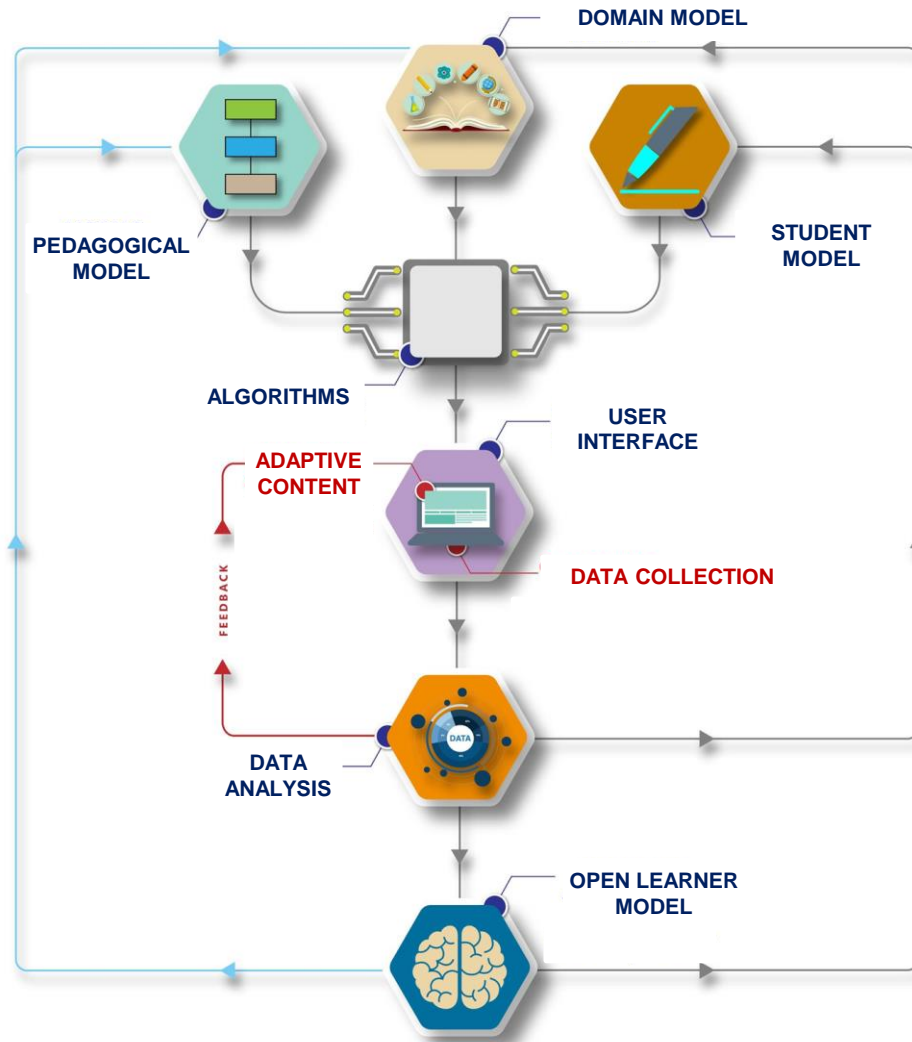
# Intelligent Tutoring Systems (ITS)



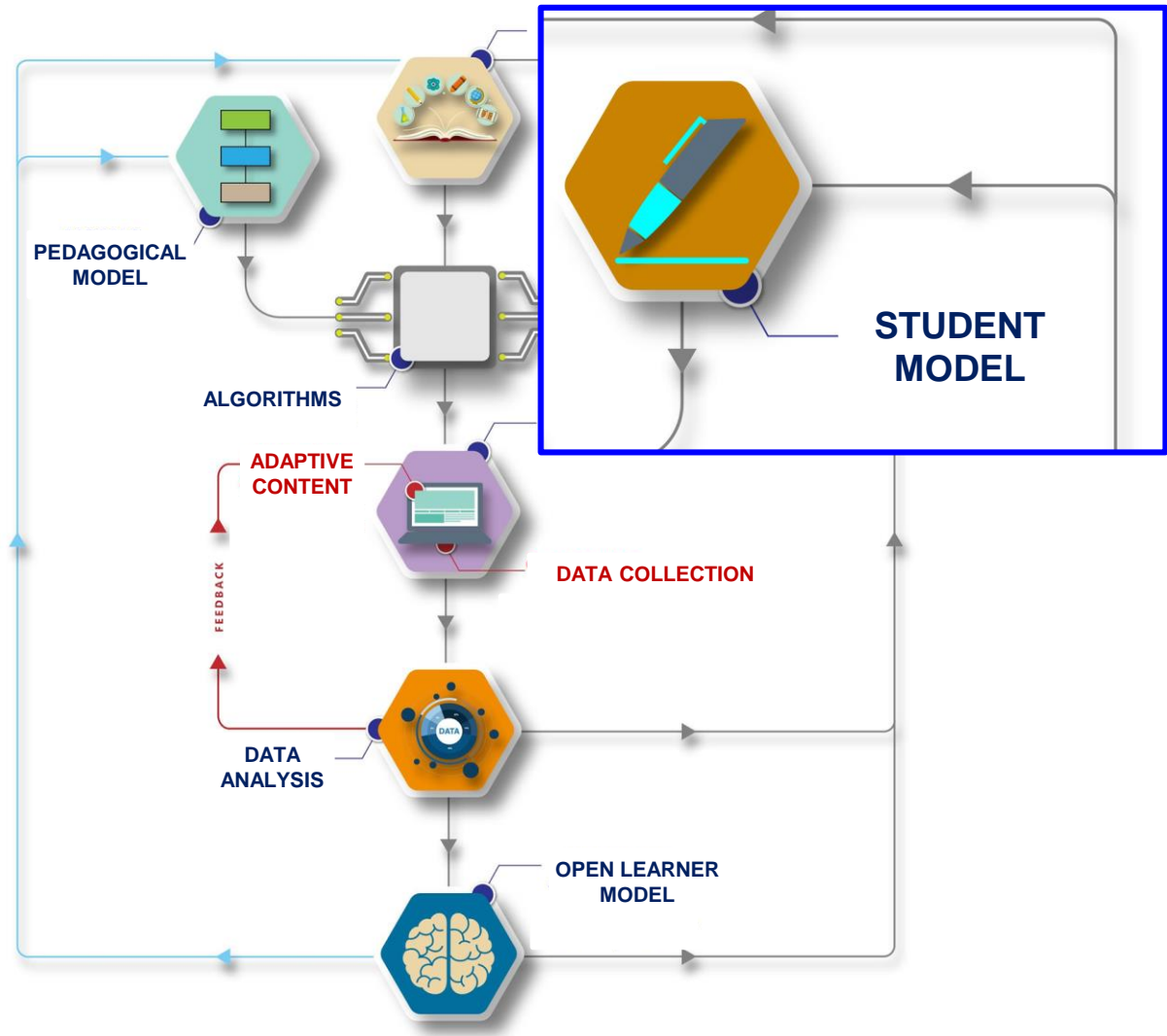
## A Definition

Intelligent Tutoring System (ITS) is a software developed to **Interact with students and teachers** via its interface presenting intelligent behaviors to **adapt** and **personalize learning**. Furthermore, it offers **step-by-step** support during problem solving to **address students needs and difficulties**.

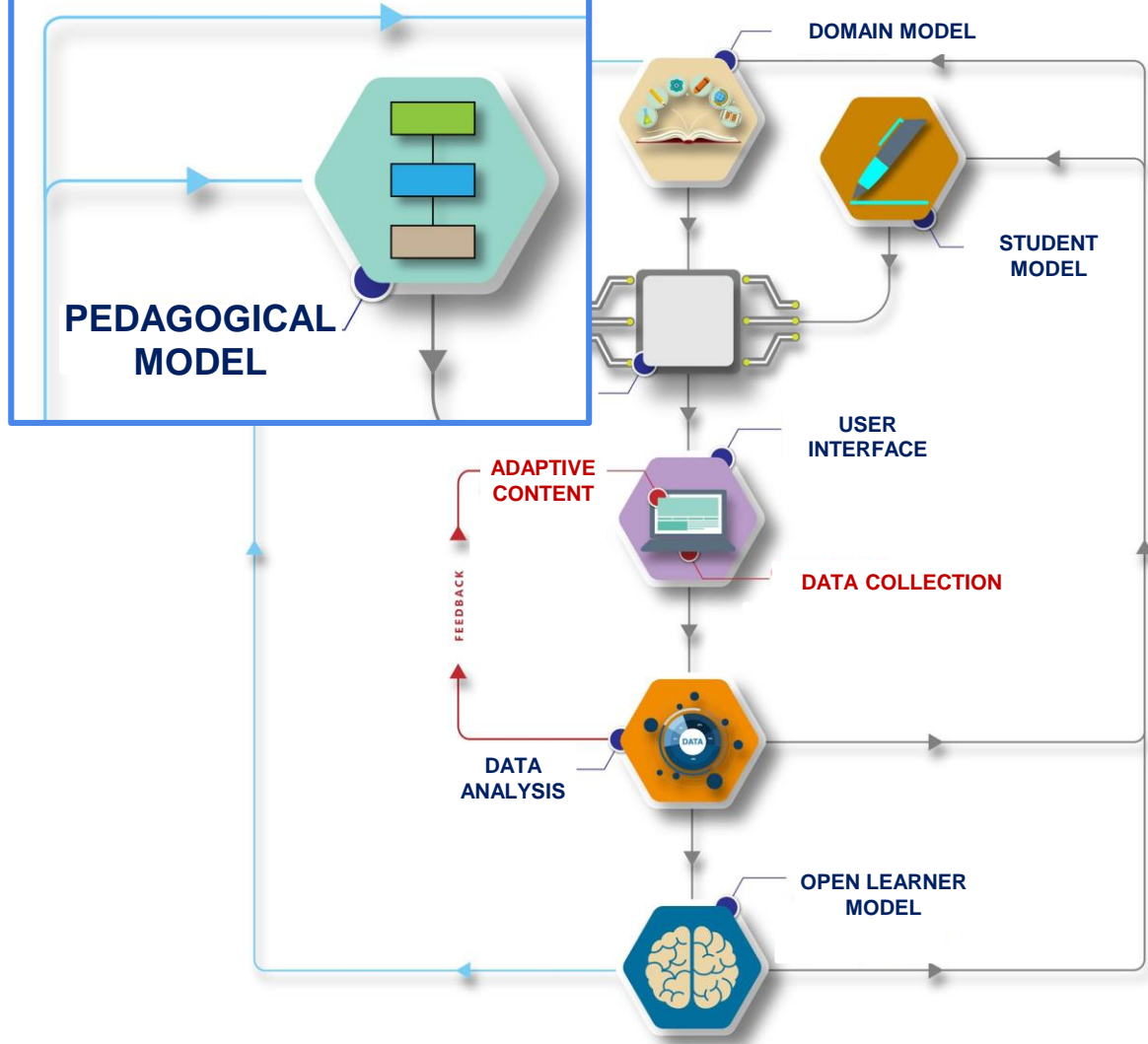
# ITS ARCHITECTURE



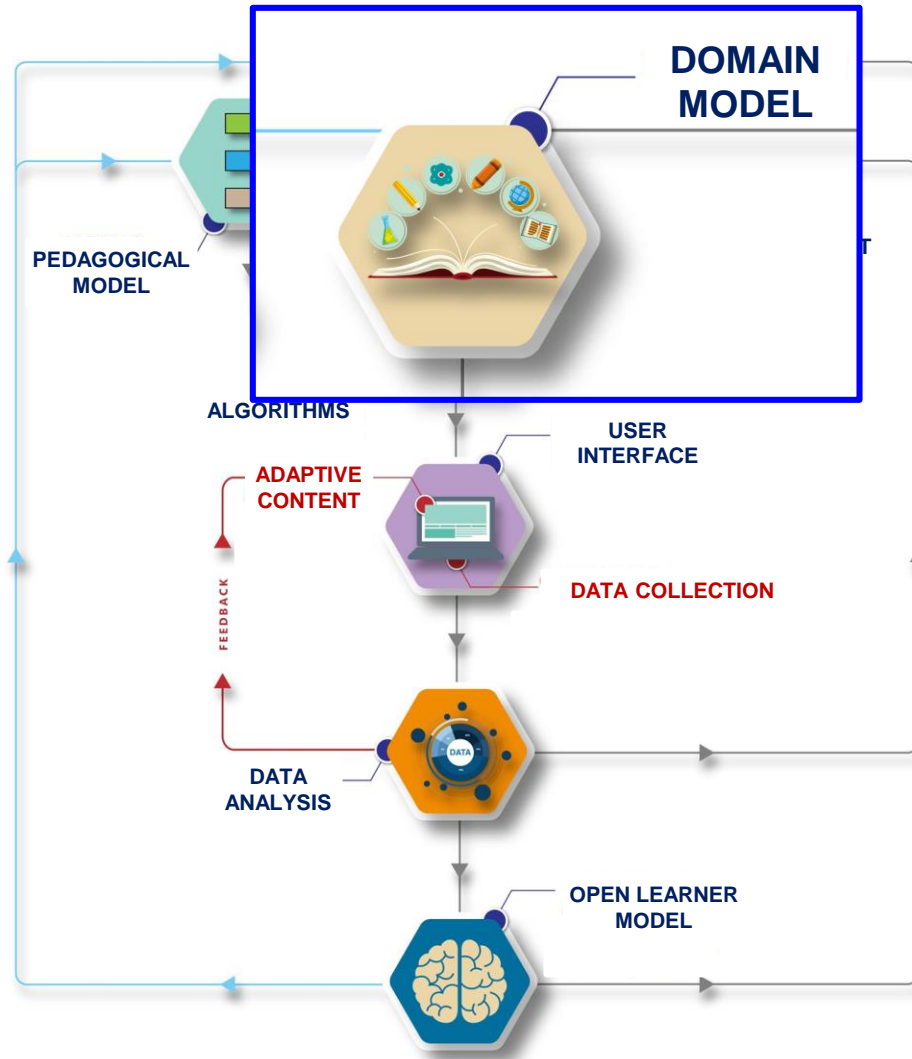
# ITS ARCHITECTURE



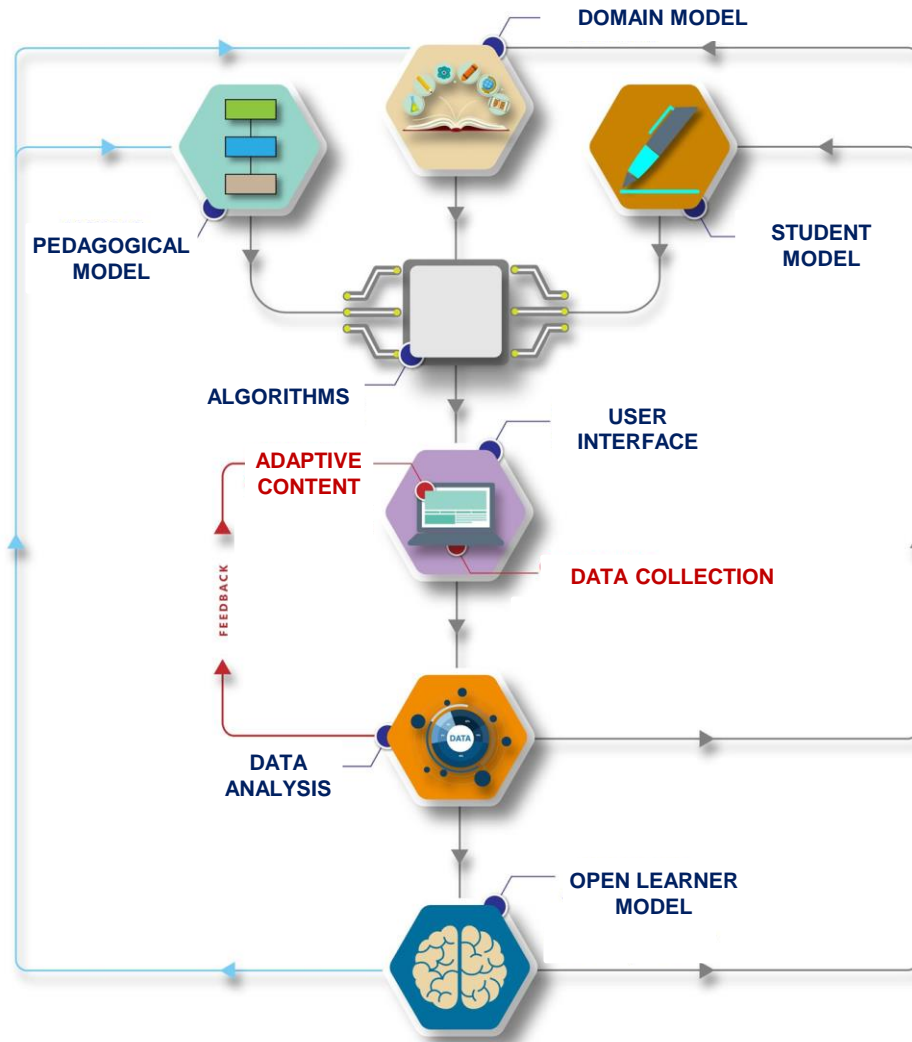
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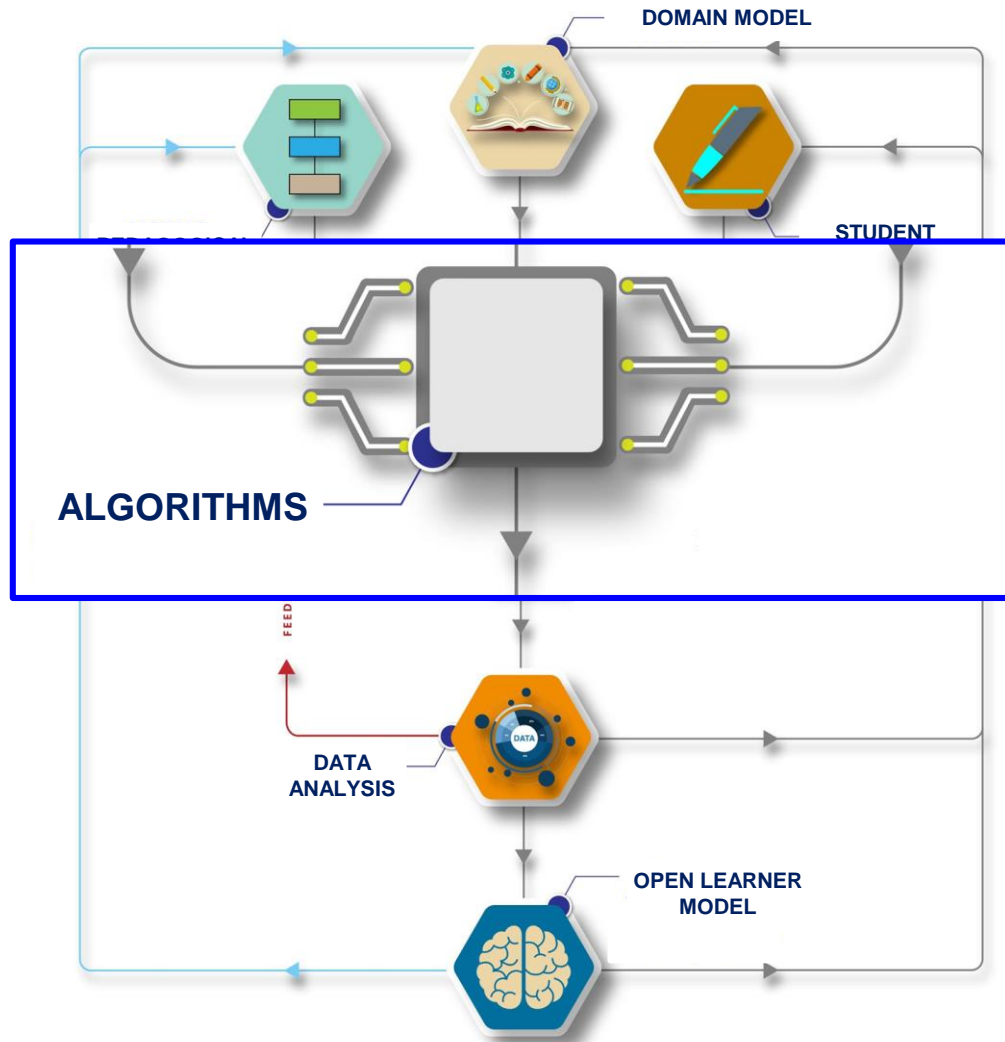


# ITS ARCHITECTURE

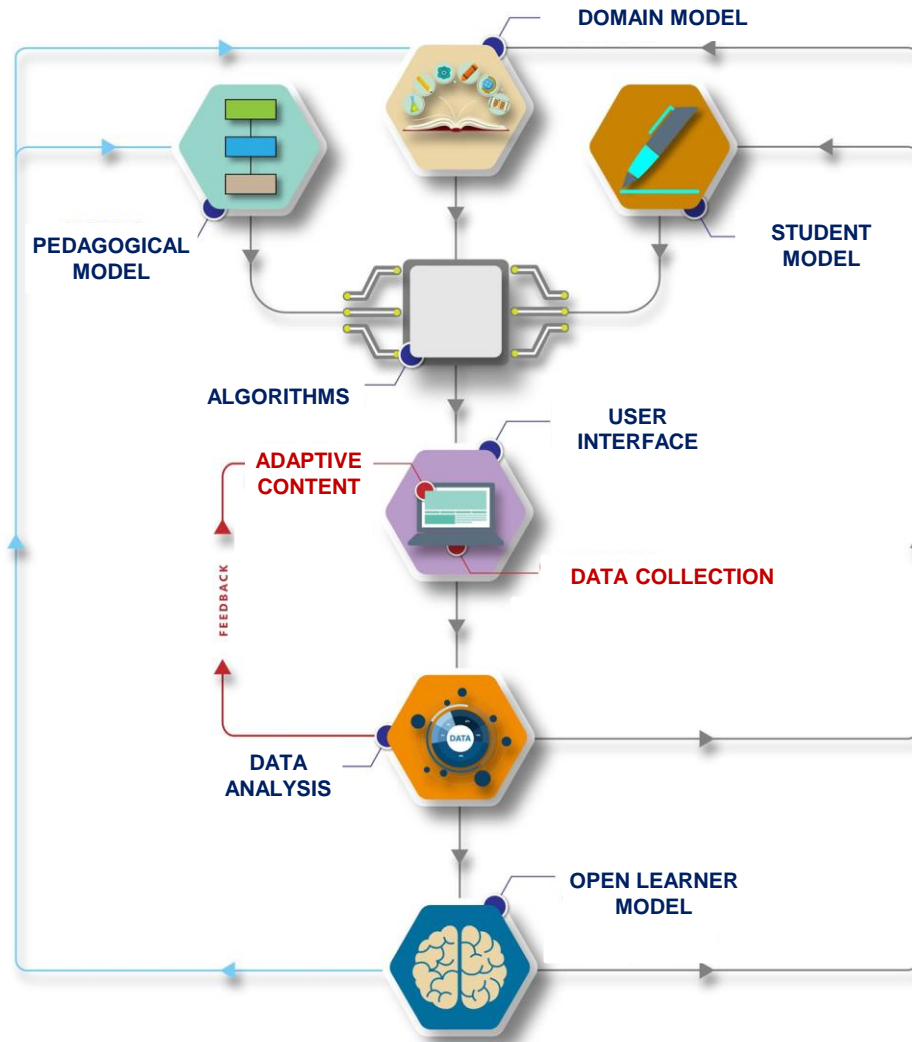




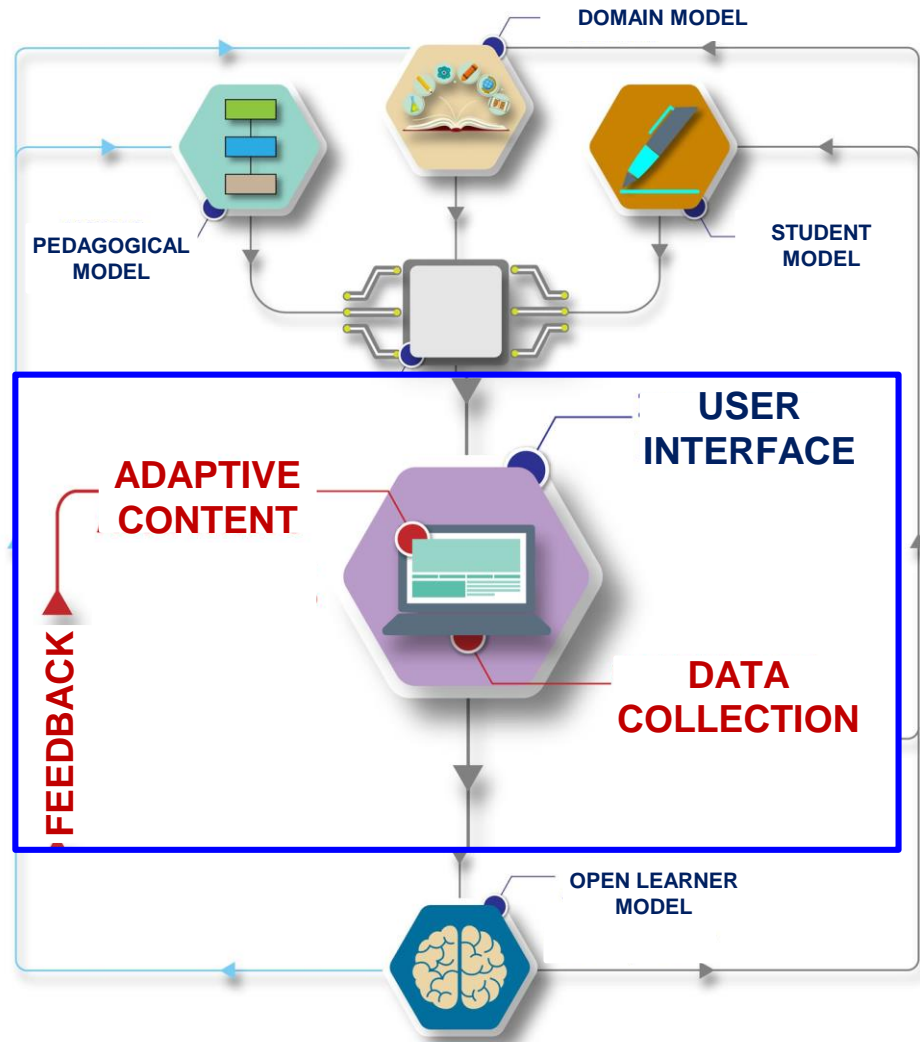
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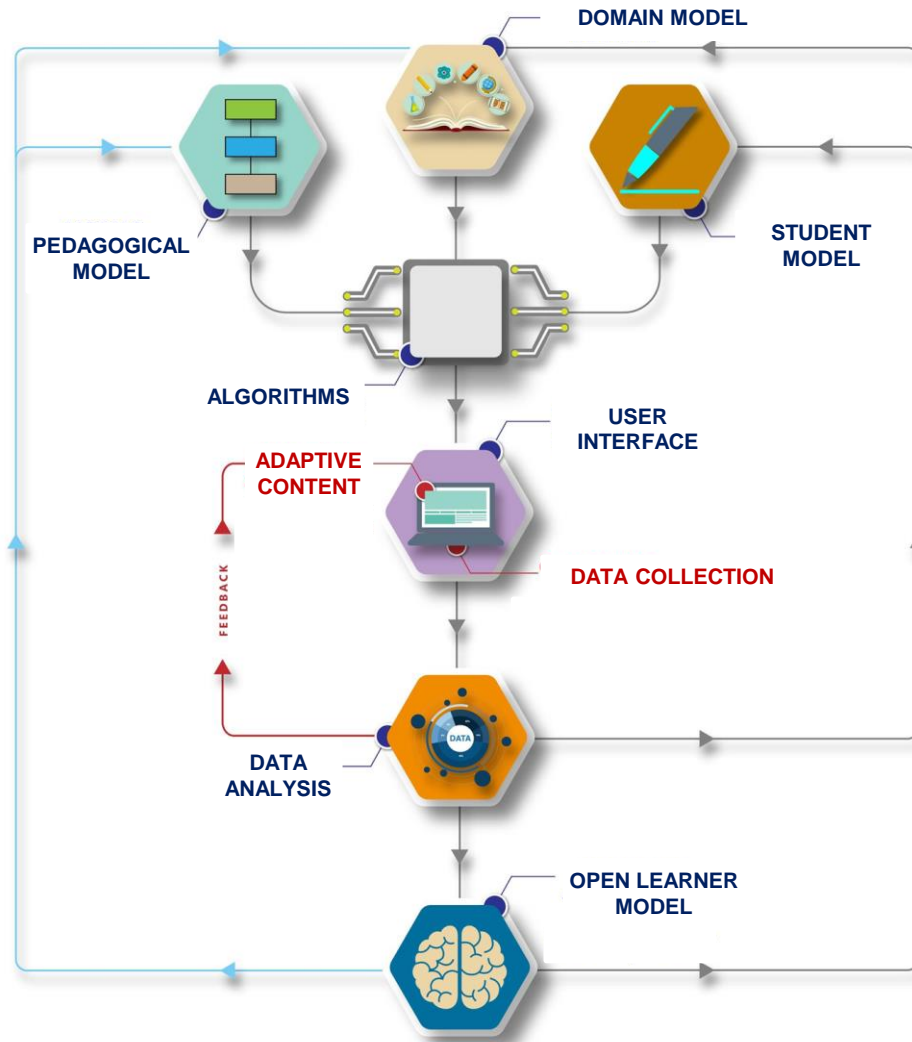
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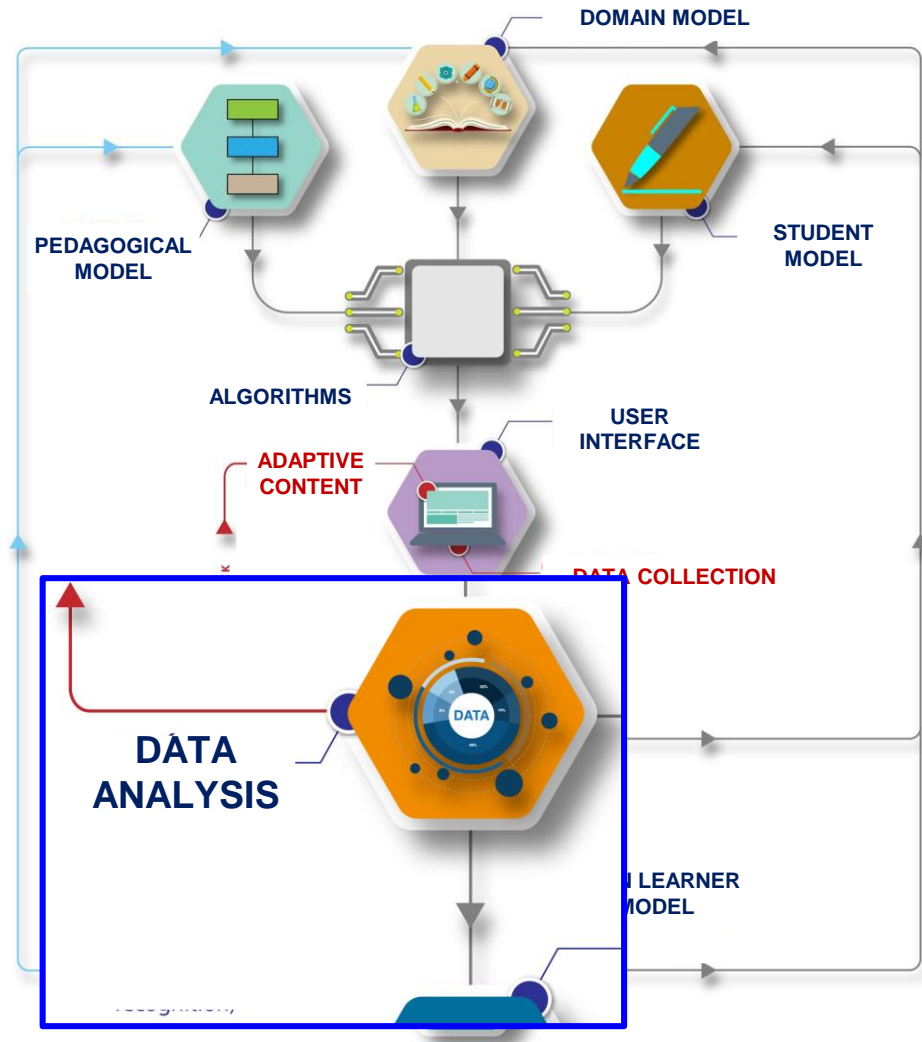
# ITS ARCHITECTURE



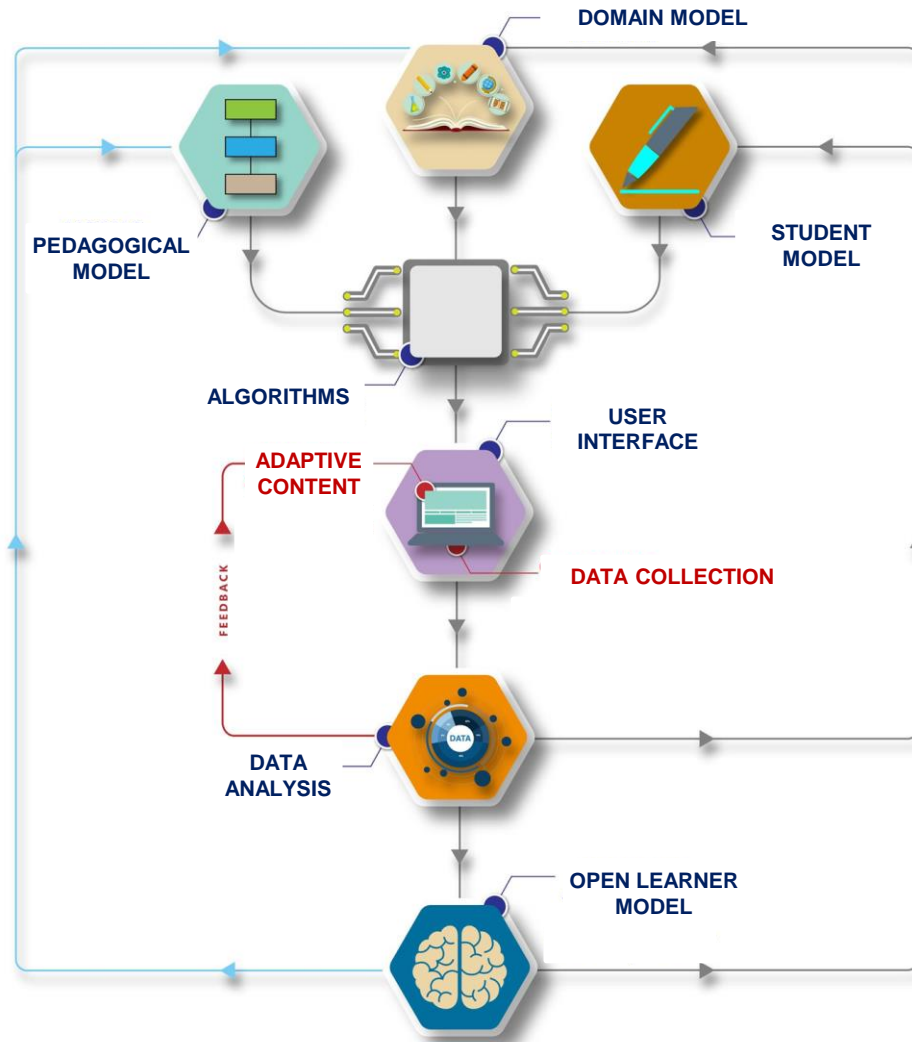
# ITS ARCHITECTURE



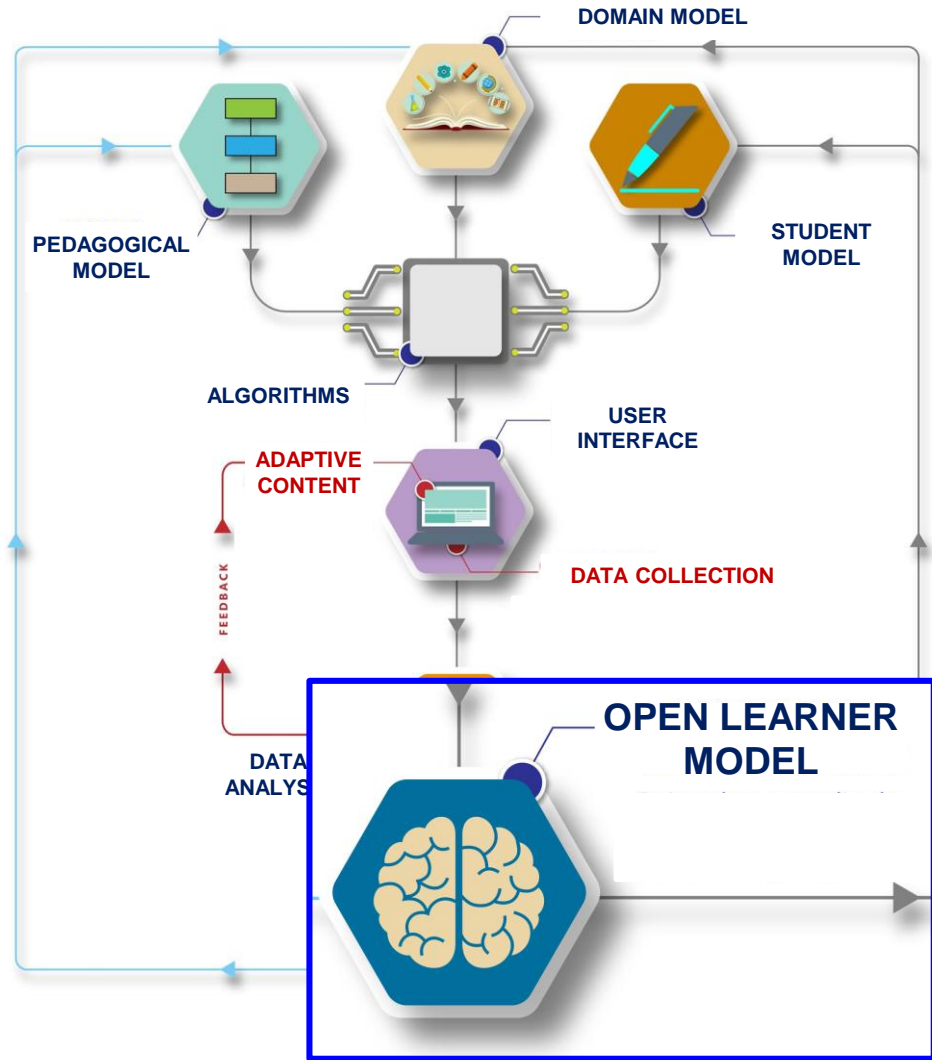
# ITS ARCHITECTURE



# ITS ARCHITECTURE



# ITS ARCHITECTURE





# Examples of ITS






# Example of Intelligent Tutoring Systems

## Mathematics

### Learning from Errors

Allison has two ribbons. One ribbon is 0.125 inches long and the other is 0.83 inches long. Allison's friend asks her to choose the longest ribbon.


Allison said this incorrect answer: I placed the numbers on a number line to see that 0.125 is the largest, so I want the 0.125 inch long ribbon.



What did Allison do wrong?  
She thinks that \_\_\_\_.

- longer decimals are smaller
- shorter decimals are smaller than zero
- shorter decimals are larger
- longer decimals are larger

Click on the line where the incorrect point should go to fix Allison's error.



Looking at the corrected number line, which ribbon is longer?

- 0.83 inches because it is closer to 1
- 0.125 inches because it is closer to 0

What advice would you give to Allison to solve the problem right next time?  
Allison, to find the longest ribbon you should pay attention to which decimal \_\_\_\_.

- is the shortest
- is the longest
- has the smallest number in the tenths place
- has the largest number in the tenths place

**Message Window**  
You've got it. Well done.

← Previous    Next →

Done



# Example of Intelligent Tutoring Systems

## Mathematics

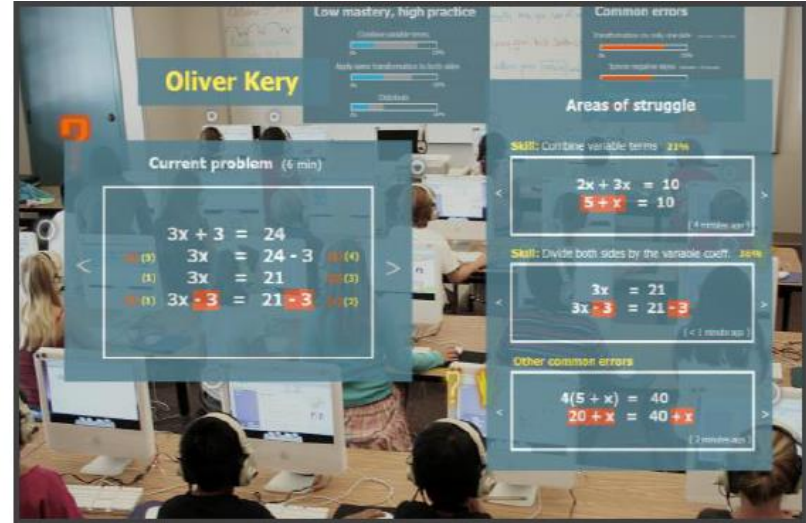
Game-based learning





# Example of Intelligent Tutoring Systems

## Mathematics - Virtual reality



<https://youtu.be/Dexjdmfv2c4?t=53>

Holstein, K., Hong, G., Tegene, M., McLaren, B. M., & Aleven, V. (2018). The Classroom as a Dashboard: Co-designing wearable cognitive augmentation for K-12 teachers. In Proceedings of the Eighth International Learning Analytics & Knowledge Conference (pp. 79-88). ACM.



# Example of Intelligent Tutoring Systems

## Chemistry

### Stoichiometry

**Stoichiometry Tutor | Worked Example** [Help](#)

**Problem Statement**

Let's convert a substance that is in milligrams to grams. We'll calculate the number of grams (g) that are in 10.6 milligrams (mg) of wood alcohol (COH<sub>4</sub>). Our result should have 3 significant figures.

**Problem**

| #    | Units | Substance        | #    | Units | Substance        | # | Units | Substance | # | Units | Substance | #      | Units | Substance        |
|------|-------|------------------|------|-------|------------------|---|-------|-----------|---|-------|-----------|--------|-------|------------------|
| 10.6 | mg    | COH <sub>4</sub> | 1    | g     | COH <sub>4</sub> |   |       |           |   |       |           | 0.0106 | g     | COH <sub>4</sub> |
|      |       |                  | 1000 | mg    | COH <sub>4</sub> |   |       |           |   |       |           |        |       |                  |

**Reason**

|                 |                 |  |  |
|-----------------|-----------------|--|--|
| Unit Conversion | Unit Conversion |  |  |
|-----------------|-----------------|--|--|

**Done**

There are some errors in the solution. The steps in red are incorrect. Please take some time to review your work. When you are ready, select the 'Next' button to move on.

**Next**

Mclaren & Isotani. (2011)



# Example of Intelligent Tutoring Systems

## Generic

## Gamification-based ITS

Disciplinas / Português  
 Clique nos assuntos para iniciar seus estudos



# Example of Intelligent Tutoring Systems

## Genetics Tutor

### Genetics

1. Determine the dominance and linkage of the disease shown and then determine the probabilities that the labeled individuals are carriers of the disease.

**1. Determine the dominance/linkage for the pedigree.**

The disease allele for this trait is recessive.

The trait is autosomal.

**2. Enter the probability the selected individuals are carriers in the fields at the right.**

**3. Finally, enter the probability VI-1 is affected.**

0.25\*0.5\*1/12\*0.5

The probability of inheriting the disease allele from V-4 is  $1/4 * 1/2 = 1/8$ .

The probability of inheriting the disease allele from V-5 is  $1/12 * 1/2 = 1/24$ .

What is the probability that VI-1 will inherit the allele from both parents?

← Previous    Next →

Hint    Done





# Example of Intelligent Tutoring Systems

## Computer Science

### RedBlackTree Tutor

## RedBlackTree Tutor

**Initial Tree**

Insert: 24

**Step 1**

What is the current node X?

What rule will you apply in this step?

**Step 2**

What is the current node X?

What rule will you apply in this step?

**Step 3**

What is the current node X?

What rule will you apply in this step?

The top-down insertion algorithm starts from the root of the tree, and moves down one level on the left or right until it finds a null node to insert the new element. Once a null node is found what becomes the current node X?



# Example of Intelligent Tutoring Systems

## Second Language Learning

7. I bought \_\_\_\_ new TV last month.

Which article (a, an, the or no article) best completes the sentence?

a

- What rule or feature is most important for deciding which article to use? -

- What rule or feature is most important for deciding which article to use? -

The noun has already been mentioned.

The noun is a single letter or number.

The noun is non-count and has a general meaning.

The noun is plural and has a general meaning.

The noun is modified with the word 'same'.

The noun is singular and has a general meaning.



Hint

← Previous

Next →





# Examples of Intelligent Tutoring Systems

Let's Interact with some ITS available at:

<https://mathtutor.web.cmu.edu/home>

- *Working with Decimals*
- *Solving Equations -> Multi-Step Linear Equations*
- *Solving Word Problems with Pictures*
- *Area, Perimeter, Circumference*

J. Sewall, V. Aleven and B. M. McLaren, (2009) "Scaling Up Programming by Demonstration for Intelligent Tutoring Systems Development: An Open-Access Web Site for Middle School Mathematics Learning," in *IEEE Transactions on Learning Technologies*, 2(2), pp. 64-78. <http://doi.ieeecomputersociety.org/10.1109/TLT.2009.22>



What are the most important characteristics in the observed ITS?



# Convention problem solving

## Problem statement

5. Starting with some number, if I multiply it by .37 and then add .22, I get 2.81. What number did I start with?

Handwritten work showing calculations:

$$\begin{array}{r} .37 \\ \times 19 \\ \hline 2.59 \\ + .22 \\ \hline 2.81 \end{array}$$
$$\begin{array}{r} .37 \\ \times 5 \\ \hline 1.85 \\ + .22 \\ \hline 2.07 \end{array}$$

Additional handwritten work includes:

$$\begin{array}{r} .37 \\ \times 2 \\ \hline .74 \\ + .22 \\ \hline .96 \end{array}$$

The number is 5.31

Koedinger & Aleven (2012)

## Final Answer



# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

Which bar represents the children and which bar represents the adults?  
Please drag the names down to the boxes below.

How many children and adults were at the concert?

**children**   **adults**



Number of children =

Number of adults =



← Previous   Next →

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
- Identify Unknown Part
- Solve Equation
- Interpret Representations





# Key Characteristics of ITS

## Problem statement

How many children and adults were at the concert?

Which bar represents the children and which bar represents the adults?  
Please drag the names down to the boxes below.

children    adults



Number of children =

Number of adults =



Hint

← Previous

Next →

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
- Identify Unknown Part
- Solve Equation
- Interpret Representations



Done



# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

How many children and adults were at the concert?

Number of children =

Number of adults =

TOTAL number of people? Please enter the number on text in that box.

children

adults

step

step

step

step

?

Hint

← Previous    Next →

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
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- Interpret Representations

Done

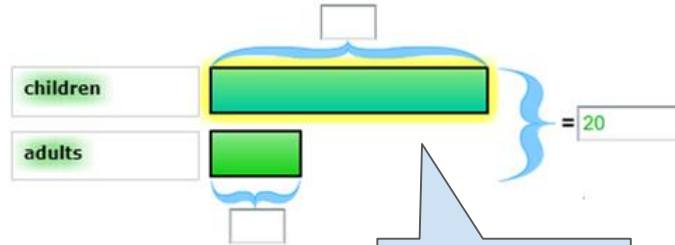


# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

How many children and adults were at the concert?

The top bar only shows the total children. Please drag-and-drop a piece from the bottom bar onto the top bar to cut it.



Number of children =

Number of adults =

Hints

Hints



Hint

You need to 'cut' the upper bar into two pieces, so it shows the difference between the number of adults and the number of children.

← Previous

Next →

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
- Identify Unknown Part
- Solve Equation
- Interpret Representations



Done



# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

How many children and adults were at the concert?

Number of children =

Number of adults =

children:

adults:

$2 \times \text{children} = 12$

$1 \times \text{adults} = 6$

$12 + 6 = 18$

$18 + 2 = 20$

Find Sum of Parts

Set-up Equation

Identify Given Value

Identify Unknown Pa

Solve Equation

Interpret Represent

Immediate feedback to each step

Immediate feedback to each step

Hint

Previous Next

scaffolding





# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

How many children and adults are there?

Number of children =

Number of adults =

2 x  =

1 x  =

14 + 6 = 20

6 + 8 = 14

children:

adults:

**Open Learner Model**

**Hint**

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
- Identify Unknown Part
- Solve Equation
- Interpret Representations

**Done**

← Previous    Next →



# Key Characteristics of ITS

Twenty people are going to a concert. There are eight more children than adults.

How many children and adults were at the concert?

Number of children =

Number of adults =

$2 \times \text{[ ]} = \text{[ 12 ]}$

$1 \times \text{[ ]} = \text{[ 6 ]}$

**Final Answer**

- Find Sum of Parts
- Set-up Equation
- Identify Given Values
- Identify Unknown Part
- Solve Equation
- Interpret Representations



# Key Characteristics of ITS

1. Step-by-step solution
2. Hints available in each step of the solution
3. Hints to the next step of the solution
4. Highlight of the correct/incorrect steps
5. Open Learner Model

These characteristics enable an ITS to provide **feedbacks** and opportunities for students' **self-regulation**



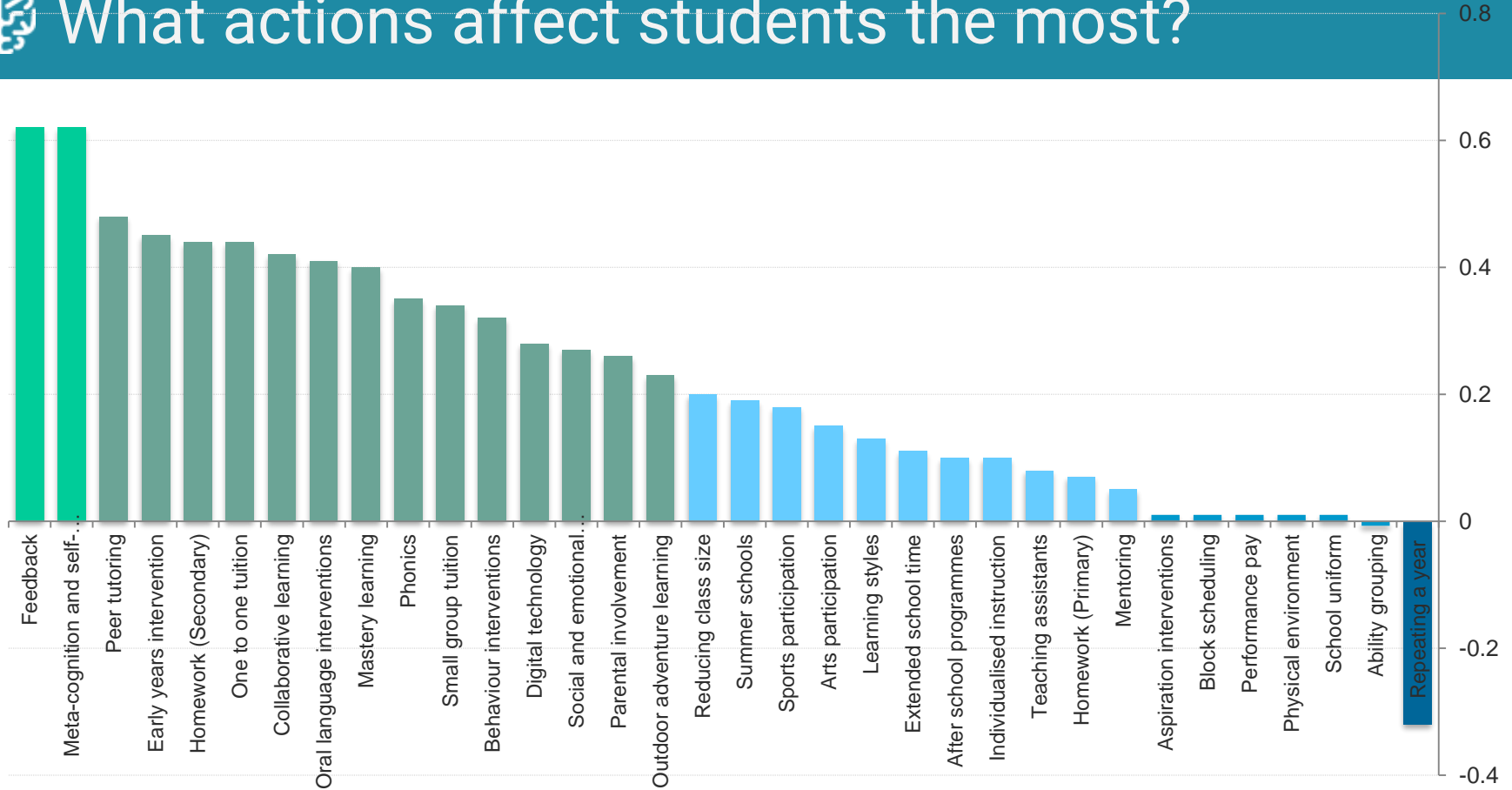
# Key Characteristics of ITS

BUT ....

Do feedback and self-regulation help  
students learn better?

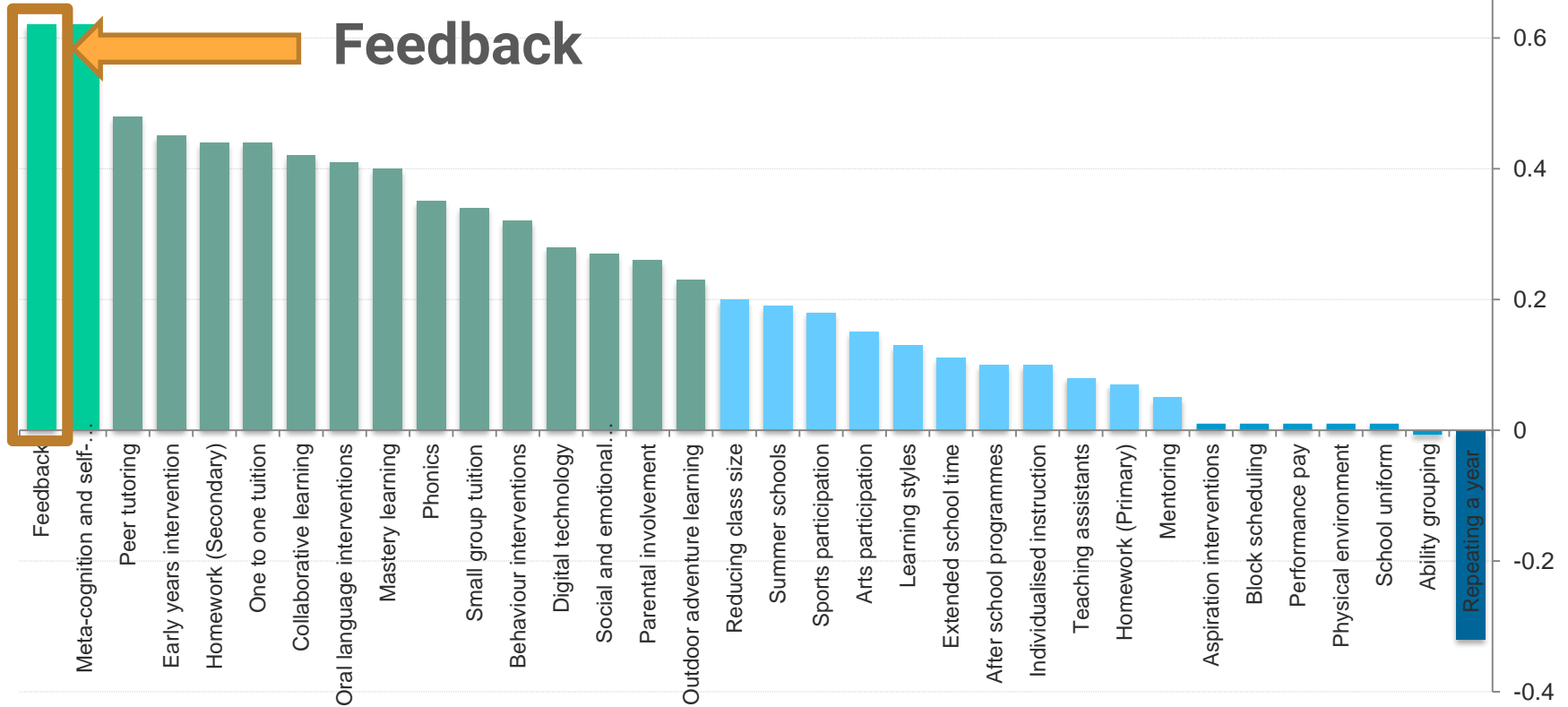


# What actions affect students the most?



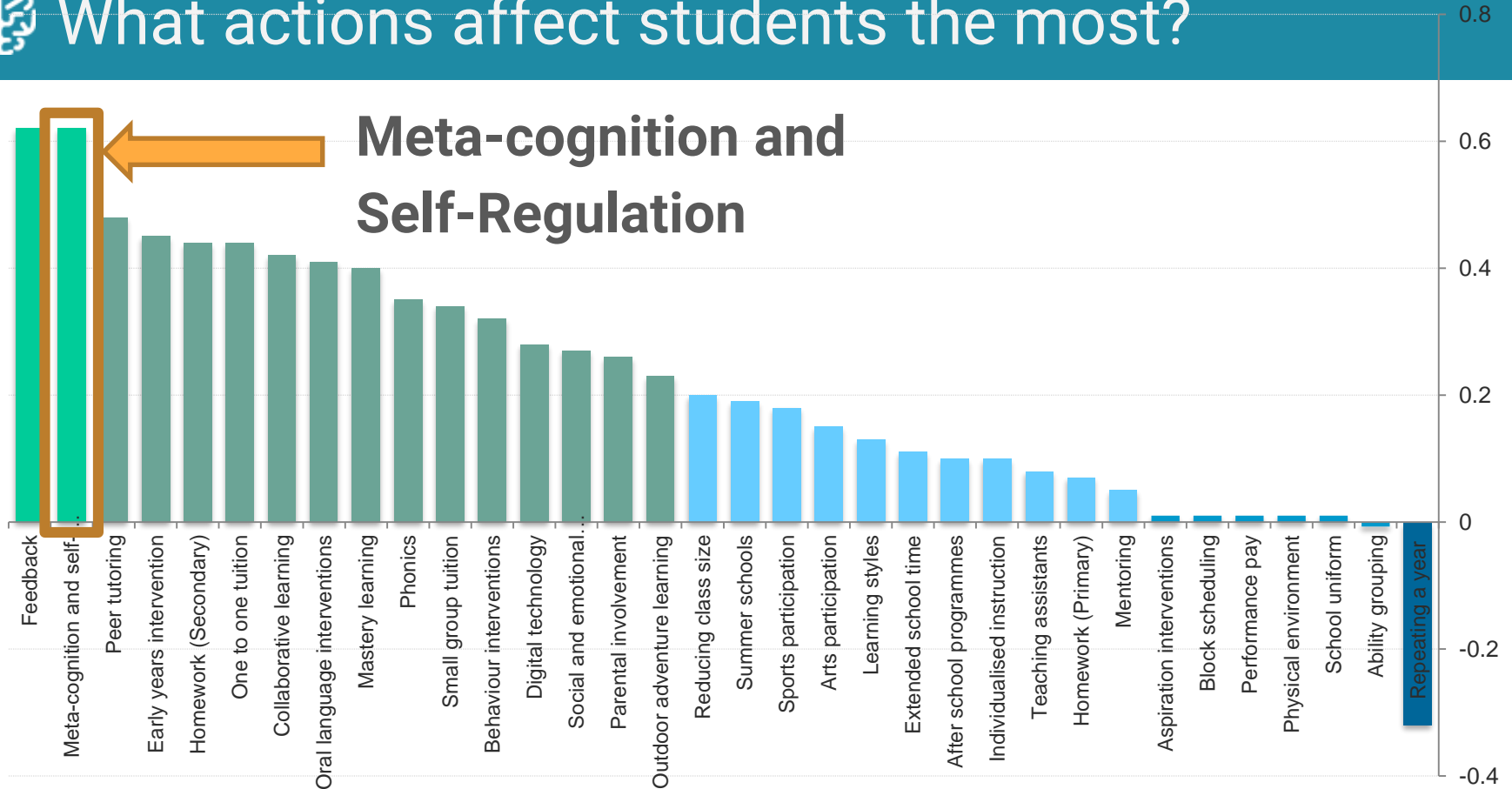


# What actions affect students the most?





# What actions affect students the most?





# The Importance of the Inner Loop

1. Step-by-step solution
2. Hints available in each step of the solution
3. Hints to the next step of the solution
4. Highlight of the correct/incorrect steps



# Effectiveness of the Inner-Loop?

## Evidências de melhoria na aprendizagem com STI e outras tecnologias

| How to adapt \ What to adapt    | STI design | Outer-Loop | Inner-Loop |
|---------------------------------|------------|------------|------------|
| Previous knowledge and growth   | ++         | ++         | ++         |
| Students' strategies and errors | ++         |            | ++         |
| Affect and motivation           | ++         | ++         | ++         |
| Self-regulation & metacognition | ++         | +          | ++         |
| Learning styles                 |            | --         |            |

Evidência  
++ : forte  
+ : fraca  
-- : contrária

Aleven, V., McLaughlin, E. A., Glenn, R. A., & Koedinger, K. R. (2017). Instruction based on adaptive learning technologies. In R. E. Mayer & P. Alexander (Eds.), Handbook of research on learning and instruction (2nd ed., pp. 522-560). New York: Routledge.  
[http://www.cs.cmu.edu/~aleven/Papers/2016/Aleven\\_et\\_al\\_Handbook2017\\_AdaptiveLearningTechnologies.pdf](http://www.cs.cmu.edu/~aleven/Papers/2016/Aleven_et_al_Handbook2017_AdaptiveLearningTechnologies.pdf)



# Outer Loop versus Inner Loop

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education*, 16(3), 227-265



# Outer Loop vs. Inner Loop

**ITS Actions**



Previous  
knowledge

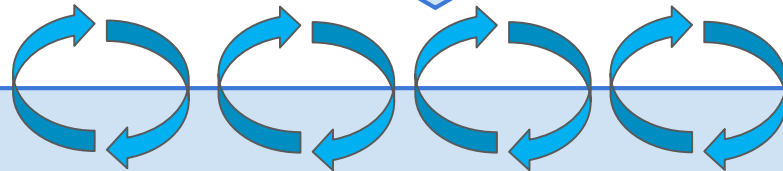
**Learning tasks**

Expected  
knowledge



# Outer Loop vs. Inner Loop

**ITS Actions**



**Inner Loop**

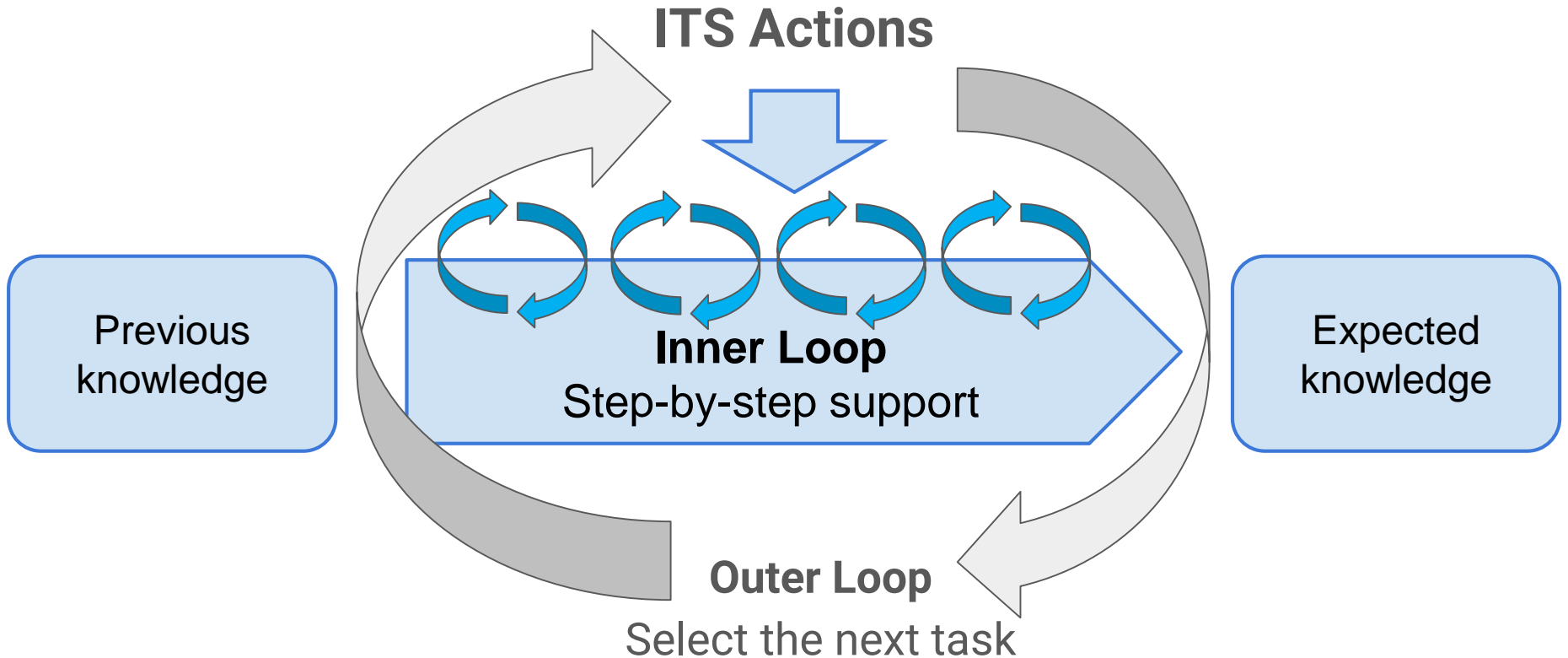
Step-by-step support

Previous  
knowledge

Expected  
knowledge



# Outer Loop vs. Inner Loop





# Outer Loop vs. Inner Loop

**Adaptation**

Previous knowledge

**ITS Actions**

**Personalization**

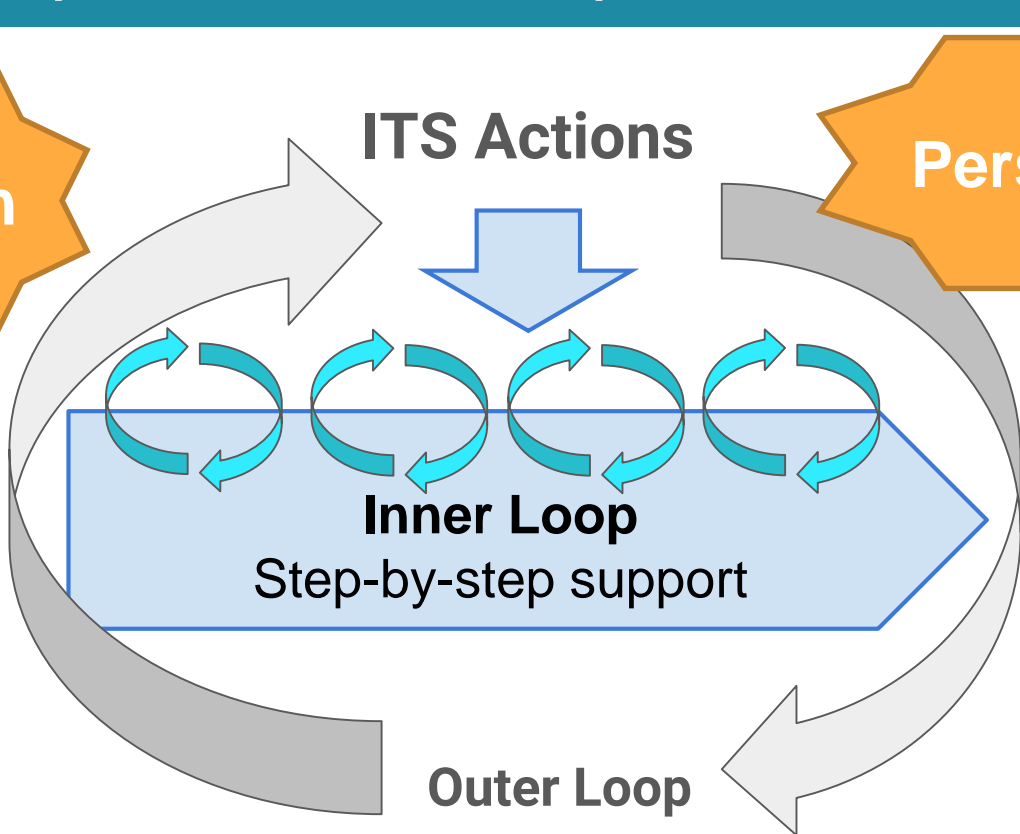
Expected knowledge

**Inner Loop**

Step-by-step support

**Outer Loop**

Select the next task



# Características essenciais - STI

According to VanLehn (2006; 2011):

Educational technologies that **have ONLY the outer loop** are called Computer-Aided Instruction (CAI), and technologies that also **have the inner loop** are called Intelligent Tutoring Systems (ITS).



# Inner Loop Approaches



There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. Minimum feedback (correct/incorrect) in each step
2. Specific feedback to each step
3. Hints to perform the next step
4. Assessment of student's knowledge
5. Review of students' solution (worked example)

There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. **Minimum feedback (correct/incorrect) in each step**
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# Inner Loop – Minimum Feedback

Example:



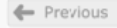
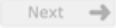
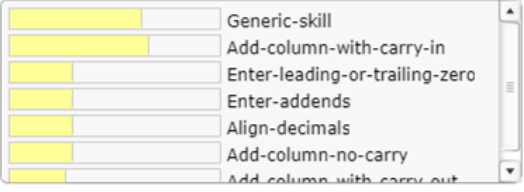

Feedback provided immediately after an action

In the example when a student have completed a step the color changes to green or red.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|       |  |  |  |   |   |   |   |   |   |
|-------|--|--|--|---|---|---|---|---|---|
|       |  |  |  |   |   |   |   |   |   |
|       |  |  |  | 8 | . | 1 | 2 | 4 |   |
| +     |  |  |  | 9 | . | 5 | 1 | 0 |   |
| <hr/> |  |  |  |   |   |   |   |   |   |
|       |  |  |  | 1 | 8 | . | 6 | 3 | 4 |

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out

There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. Minimum feedback (correct/incorrect) in each step
2. **Specific feedback to each step**
3. Hints to perform the next step
4. Assessment of student's knowledge
5. Review of students' solution (worked example)

# Inner Loop – Specific Feedback

Exemple:

[Working with Decimals ->](#)  
[Decimal Addition and](#)  
[Subtraction III](#)

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|       |  |  |  |   |   |   |   |   |
|-------|--|--|--|---|---|---|---|---|
|       |  |  |  |   |   |   |   |   |
|       |  |  |  | 8 | . | 1 | 2 | 4 |
| +     |  |  |  | 9 | . | 5 | 1 | 0 |
| <hr/> |  |  |  |   |   |   |   |   |
|       |  |  |  |   | . | 6 | 3 | 4 |



Hint



Instructions

← Previous

Next →

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
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- Add-column-with-carry-out



Done

# Inner Loop – Specific Feedback

## 1. Specific hint to a common error.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|   |  |  |  |    |   |   |   |   |
|---|--|--|--|----|---|---|---|---|
|   |  |  |  |    |   |   |   |   |
|   |  |  |  | 8  | . | 1 | 2 | 4 |
| + |  |  |  | 9  | . | 5 | 1 | 0 |
|   |  |  |  | 17 | . | 6 | 3 | 4 |



Hint



Instructions

The number you've entered is the sum of 9+8, however you need to carry 10 into the next column using the carryboxes.

← Previous    Next →

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out



Done

# Inner Loop – Specific Feedback

2. On demand specific hints to complete a step:

Hints can be procedural or conceptual. In this example, we have a procedural hint.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|                      |                      |                      |                      |                      |                      |                      |                      |                      |
|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | 8                    | .                    | 1                    | 2                    | 4                    |
| +                    | <input type="text"/> | <input type="text"/> | <input type="text"/> | 9                    | .                    | 5                    | 1                    | 0                    |
| <hr/>                |                      |                      |                      |                      |                      |                      |                      |                      |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | .                    | 6                    | 3                    | 4                    |

**? Hint** Add the digits in the ones places and enter the sum here. Don't forget to add any values carried!

**i Instructions** [← Previous](#) [Next →](#)

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out

**✓ Done**

# Inner Loop – Specific Feedback

On demand specific hints to complete a step:

If students require more assistant, the hints become more specific.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|       |  |  |  |   |   |   |   |   |
|-------|--|--|--|---|---|---|---|---|
|       |  |  |  |   |   |   |   |   |
|       |  |  |  | 8 | . | 1 | 2 | 4 |
| +     |  |  |  | 9 | . | 5 | 1 | 0 |
| <hr/> |  |  |  |   |   |   |   |   |
|       |  |  |  |   | . | 6 | 3 | 4 |



Hint

The digits in the ones places are 8 and 9, and nothing was carried from the sum of the tenths column.  $8+9=17$ , so please enter a 7 here and carry a 1 over to the tens column (10 ones=1 ten).



Instructions

← Previous

Next →

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out



Done



# Inner Loop – Specific Feedback

On demand specific hints to complete a step:

Hints usually request students to think about what should be done to complete the step.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|       |  |  |  |   |   |   |   |   |
|-------|--|--|--|---|---|---|---|---|
|       |  |  |  |   |   |   |   |   |
|       |  |  |  | 8 | . | 1 | 2 | 4 |
| +     |  |  |  | 9 | . | 5 | 1 | 0 |
| <hr/> |  |  |  |   |   |   |   |   |
|       |  |  |  | 7 | . | 6 | 3 | 4 |



If you carry a value over from adding the ones values, please enter it here.



[← Previous](#) [Next →](#)

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out



# Inner Loop – Specific Feedback

On demand specific hints to complete a step:


Hints also consider the previous completed steps.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|                      |                      |                      |                      |                      |                      |                      |                      |                      |
|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | 8                    | .                    | 1                    | 2                    | 4                    |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | 9                    | .                    | 5                    | 1                    | 0                    |
| <hr/>                |                      |                      |                      |                      |                      |                      |                      |                      |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | 7                    | .                    | 6                    | 3                    | 4                    |

 **Hint**  
One ten was carried over from the addition of 8 ones and 9 ones. Please enter 1.

 **Instructions**

[← Previous](#) [Next →](#)

- Generic-skill
- Add-column-with-carry-in
- Enter-leading-or-trailing-zero
- Enter-addends
- Align-decimals
- Add-column-no-carry
- Add-column-with-carry-out



# Inner Loop – Specific Feedback

On demand specific hints to complete a step:

Hints become more specific after each request until reaching a point where the ITS presents exactly what should be the input.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|   |  |  |   |   |   |   |   |   |
|---|--|--|---|---|---|---|---|---|
|   |  |  | 1 |   |   |   |   |   |
|   |  |  |   | 8 | . | 1 | 2 | 4 |
| + |  |  |   | 9 | . | 5 | 1 | 0 |
|   |  |  |   |   |   |   |   |   |
|   |  |  |   | 7 | . | 6 | 3 | 4 |

**?**  
Hint

**i**  
Instructions

There are no digits in the tens places except for 1 ten that was carried over from addition in the ones column, so please enter 1 here.

← Previous    Next →

- Generic-skill
- Add-column-with-carry-in
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- Enter-addends
- Align-decimals
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# Inner Loop – Specific Feedback





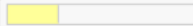
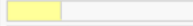
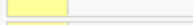
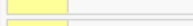
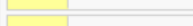



On demand specific hints to complete a step:

In the end, students can visualize and revise the whole process to reach the solution (known as *worked-example*<sup>1</sup>)

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|   |  |  |   |       |   |   |   |   |
|---|--|--|---|-------|---|---|---|---|
|   |  |  | 1 |       |   |   |   |   |
|   |  |  |   | 8     | . | 1 | 2 | 4 |
| + |  |  |   | 9     | . | 5 | 1 | 0 |
|   |  |  |   | <hr/> |   |   |   |   |
|   |  |  | 1 | 7     | . | 6 | 3 | 4 |

     Generic-skill  
 Add-column-with-carry-in  
 Enter-leading-or-trailing-zero  
 Enter-addends  
 Align-decimals  
 Add-column-no-carry  
 Add-column-with-carry-out 

[1] [https://doi.org/10.1007/978-3-642-21869-9\\_30](https://doi.org/10.1007/978-3-642-21869-9_30)

There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. Minimum feedback (correct/incorrect) in each step
2. Specific feedback to each step
- 3. Hints to perform the next step**
4. Assessment of student's knowledge
5. Review of students' solution (worked example)

# Inner Loop

Example:

Highlight the best next step to be executed.

You are trying to eat healthy foods. For breakfast, you eat 8.124 grams of protein. For lunch, you eat 9.51 grams of protein. How much total protein did you eat at breakfast and lunch?

Use these boxes to recombine values:

|       |  |  |  |   |   |   |   |   |
|-------|--|--|--|---|---|---|---|---|
|       |  |  |  |   |   |   |   |   |
|       |  |  |  | 8 | . | 1 | 2 | 4 |
| +     |  |  |  | 9 | . | 5 | 1 | 0 |
| <hr/> |  |  |  |   |   |   |   |   |
|       |  |  |  | 7 | . | 6 | 3 | 4 |



If you carry a value over from adding the ones values, please enter it here.



[← Previous](#) [Next →](#)

- Generic-skill
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There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. Minimum feedback (correct/incorrect) in each step
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3. Hints to perform the next step
- 4. Assessment of student's knowledge**
5. Review of students' solution (worked example)



# Inner Loop - Assessment of student's knowledge

- **WHAT** to assess?

**WHAT**



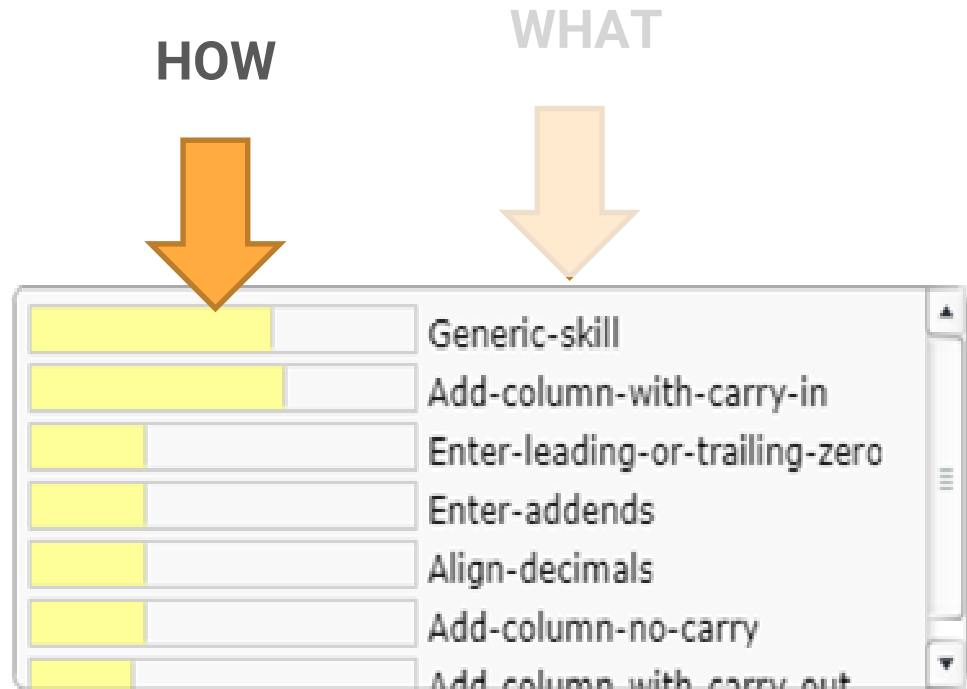
|                          |                                |
|--------------------------|--------------------------------|
| <input type="checkbox"/> | Generic-skill                  |
| <input type="checkbox"/> | Add-column-with-carry-in       |
| <input type="checkbox"/> | Enter-leading-or-trailing-zero |
| <input type="checkbox"/> | Enter-addends                  |
| <input type="checkbox"/> | Align-decimals                 |
| <input type="checkbox"/> | Add-column-no-carry            |
| <input type="checkbox"/> | Add-column-with-carry-out      |





# Inner Loop - Assessment of student's knowledge

- WHAT to assess?
- **HOW** to assess?





# Inner Loop - Assessment of student's knowledge

- Knowledge tracing: Modeling the acquisition of procedural knowledge (1994)  
<https://doi.org/10.1007/BF01099821>
- Bayesian knowledge tracing, logistic models, and beyond: an overview of learner modeling techniques  
<https://doi.org/10.1007/s11257-017-9193-2>

There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will present 5 of them:

1. Minimum feedback (correct/incorrect) in each step
2. Specific feedback to each step
3. Hints to perform the next step
4. Assessment of student's knowledge
5. **Review of students' solution (worked example)**



# Inner Loop - Review of students' solution

Example:

$$\begin{array}{l} \boxed{5x+2} = \boxed{2x+8} \\ \boxed{\phantom{5x+2}} = \boxed{\phantom{2x+8}} \end{array}$$

Solving Equations ->

Solving Multi-Step Linear

Equations containing

Variables and Constants on

both sides



# Inner Loop - Review of students' solution

Example:

Ask students to think about each problem step

$$\begin{array}{l} \boxed{5x+2} = \boxed{2x+8} \\ \boxed{\phantom{5x+2}} = \boxed{\phantom{2x+8}} \\ \boxed{5x+2} = \boxed{2x+8} \\ \boxed{5x} = \boxed{2x+6} \end{array}$$

What have you done? ▼



# Inner Loop - Review of students' solution

Example:

Ask students to think about each problem step

$$\begin{array}{l} \boxed{5x+2} = \boxed{2x+8} \\ \boxed{\phantom{5x+2}} = \boxed{\phantom{2x+8}} \end{array}$$

$$\begin{array}{l} \boxed{5x+2} = \boxed{2x+8} \\ \boxed{5x} = \boxed{2x+6} \end{array}$$

$$\begin{array}{l} \boxed{5x+2} = \boxed{2x+8} \\ \boxed{5x} = \boxed{2x+6} \end{array}$$

What have you done? ▾

subtract [?] from both sides ▾



# Inner Loop - Review of students' solution

Example:

Ask students to think about each problem step

$$\boxed{5x+2} = \boxed{2x+8}$$

$$\boxed{\phantom{5x+2}} = \boxed{\phantom{2x+8}}$$

$$\boxed{5x+2} = \boxed{2x+8}$$

$$\boxed{5x} = \boxed{2x+6}$$

$$\boxed{5x+2} = \boxed{2x+8}$$

$$\boxed{5x} = \boxed{2x+6}$$

$$\boxed{5x+2} = \boxed{2x+8}$$

$$\boxed{5x} = \boxed{2x+6}$$

$$\boxed{\phantom{5x+2}} = \boxed{\phantom{2x+8}}$$

What have you done? ▾

subtract [?] from both sides ▾

subtract [?] from both sides ▾



# Inner Loop - Review of students' solution

## Example:

1. Show the list of steps
2. Show the minimum feedback
3. Give opportunities to think about each step

|                                   |   |                                     |
|-----------------------------------|---|-------------------------------------|
| <input type="text" value="5x+2"/> | = | <input type="text" value="2x+8"/>   |
| <input type="text" value="5x"/>   | = | <input type="text" value="2x + 6"/> |
| <input type="text" value="3x"/>   | = | <input type="text" value="6"/>      |
| <input type="text" value="x"/>    | = | <input type="text" value="2"/>      |

|   |                                 |
|---|---------------------------------|
| <input type="text" value="subtract [?] from both sides"/> | <input type="text" value="2"/>  |
| <input type="text" value="subtract [?] from both sides"/> | <input type="text" value="2x"/> |
| <input type="text" value="divide both sides by [?]"/>     | <input type="text" value="3"/>  |





# Inner Loop - Review of students' solution

## Example:

1. Show the list of steps
2. Show the minimum feedback
3. Give opportunities to think about each step

Use these boxes to recombine values:

|       |  |  |   |   |   |   |   |   |
|-------|--|--|---|---|---|---|---|---|
|       |  |  | 1 |   |   |   |   |   |
|       |  |  |   | 8 | . | 1 | 2 | 4 |
| +     |  |  |   | 9 | . | 5 | 1 | 0 |
| <hr/> |  |  |   |   |   |   |   |   |
|       |  |  | 1 | 7 | . | 6 | 3 | 4 |



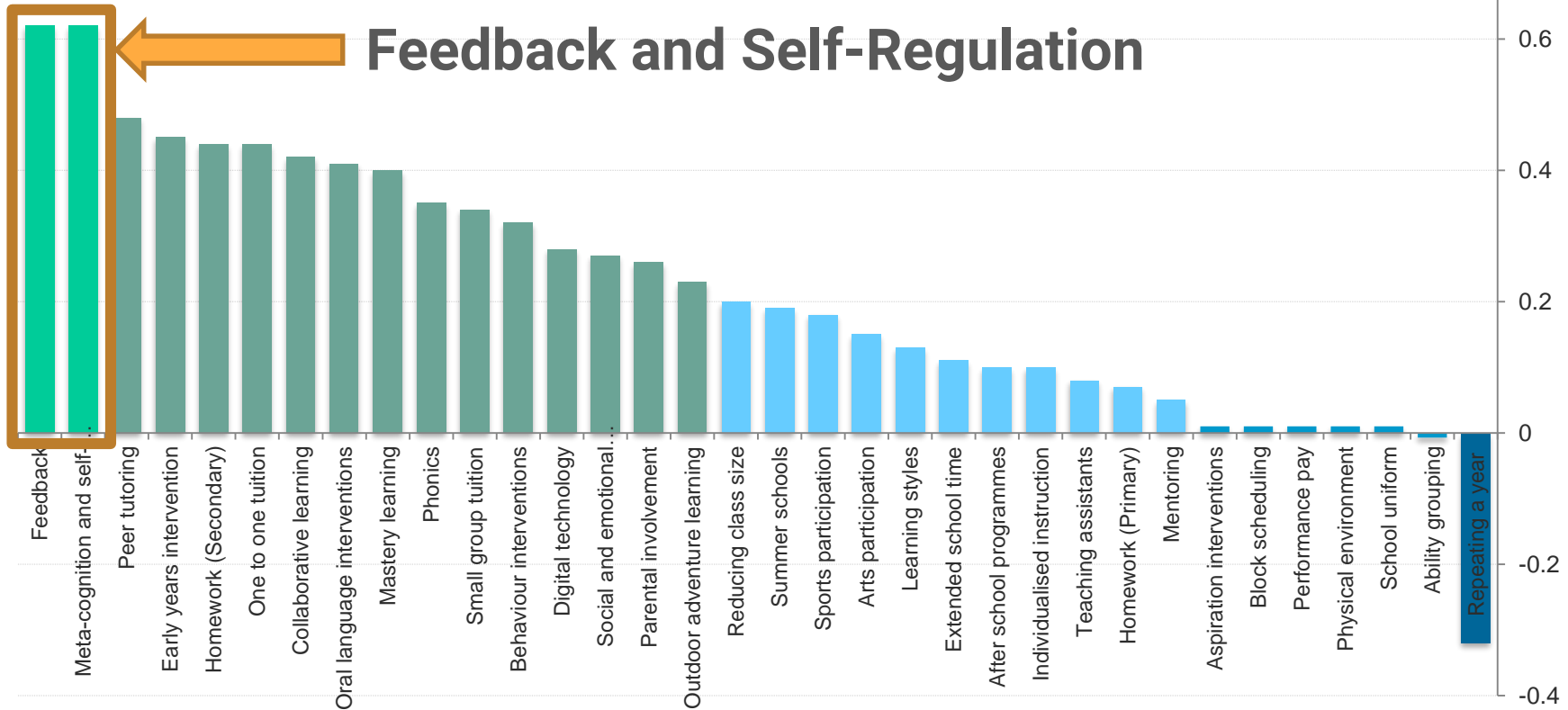
# Inner Loop

In Summary,

The inner loop helps a student to:

- 1) **Think** about each problem step (i.e. self-regulated learning)
- 2) **Solve** each problem step (by giving hints and feedback)

# The importance of the inner loop





# Challenges to apply the inner loop in ITS



# Challenges

- Generate step-by-step feedback/hint is one of the most demanding, time-consuming, expensive and complex activity during the authoring of na ITS.
  - Each task needs to be associated with adequate knowledge components and each step with hints/feedback.
- Currently, the **inner loop is manually built** or only with a small degree of automation.



# Challenges

Inner-loop, as currently implemented in most authoring tools, seems to not engage students:

- Based on text
- Fixed on the interface without considering the task
- Is not personalized considering students' characteristics
  - emotional status
  - students' susceptibility to influence principles
  - Player types, etc



# Challenges

1. How to develop an approach to “**automatize**” and speed up the implementation of the inner loop to any content and domain?
  - Human-computation
2. How to personalize the inner loop to better engage students during the learning process?
  - Gamification
  - Persuasion
  - Multimedia learning



# Ongoing Research





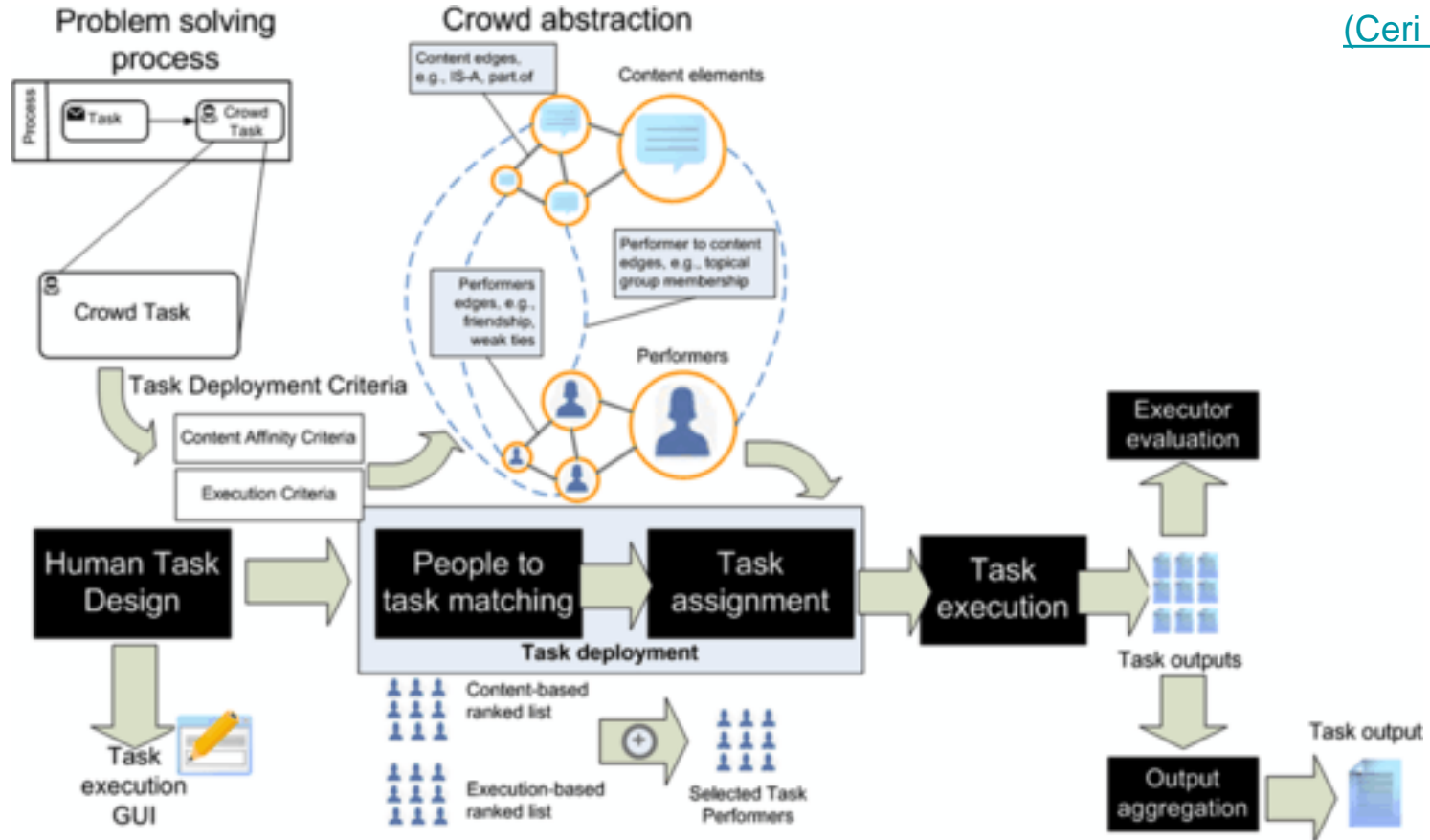
# Challenges

1. How to develop an approach to “**automatize**” and speed up the implementation of the inner loop to any content and domain?
  - Human-computation
2. How to personalize the inner loop to better engage students during the learning process?
  - Gamification
  - Multimedia learning



# Creating the inner loop with human computation

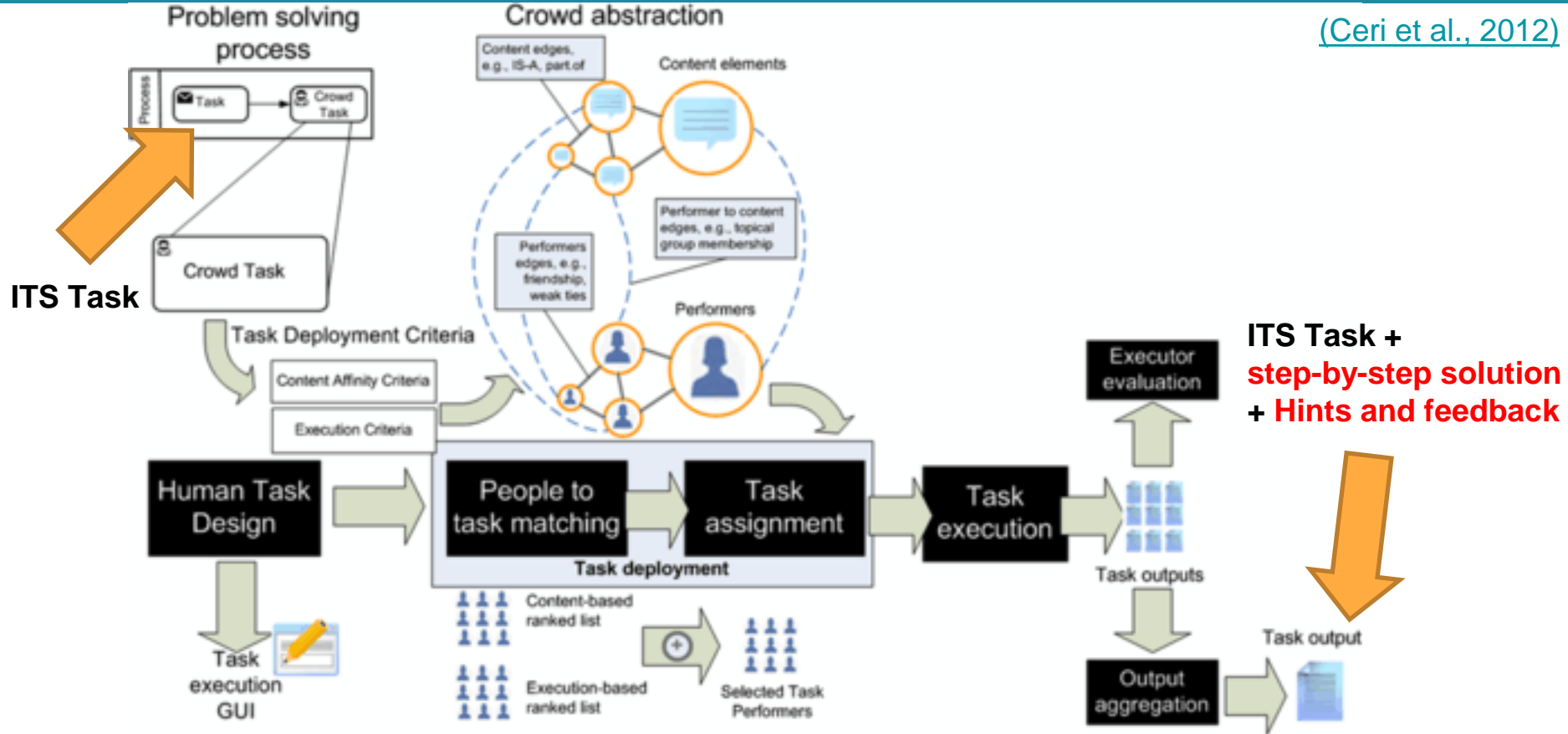
(Ceri et al., 2012)





# Creating the inner loop with human computation

(Ceri et al., 2012)

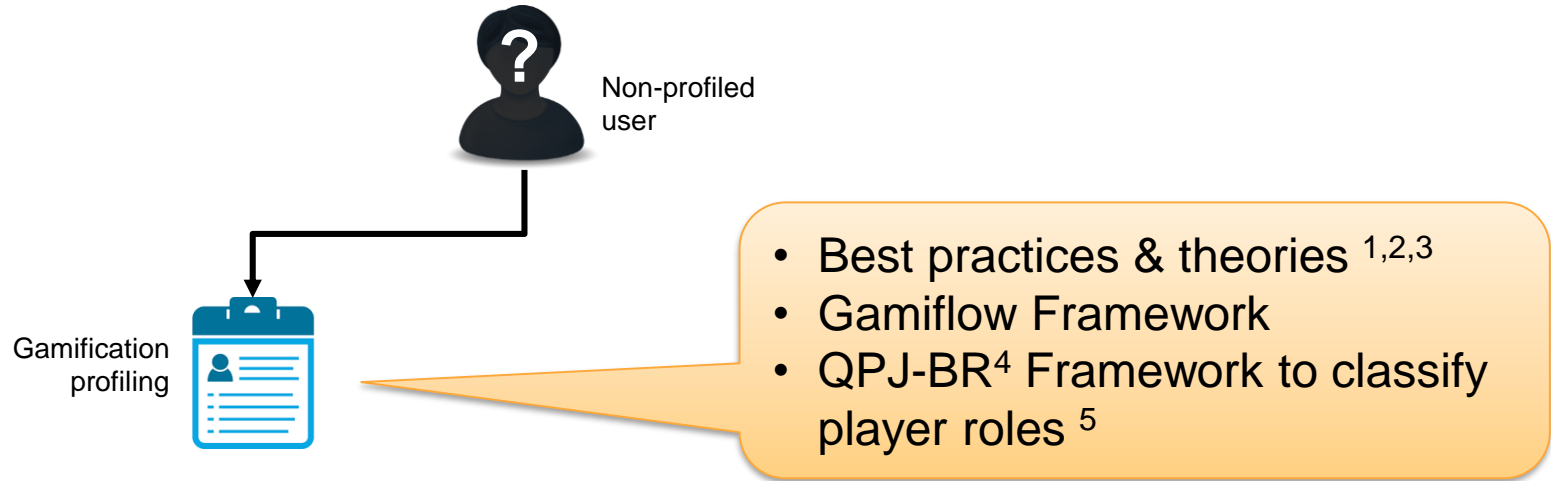




# Challenges

1. How to develop an approach to “**automatize**” and speed up the implementation of the inner loop to any content and domain?
  - Human-computation
2. How to personalize the inner loop to better engage students during the learning process?
  - Gamification
  - Multimedia learning

# Approach to personalized inner loop design



**1 BORGES, S. S.; DURELLI, V. H. S.; REIS, H. M.; ISOTANI, S. A systematic mapping on gamification applied to education. In: Proceedings of the 29th Annual ACM Symposium on Applied Computing - SAC '14. New York, USA: ACM Press, 2014. P. 216–222.**

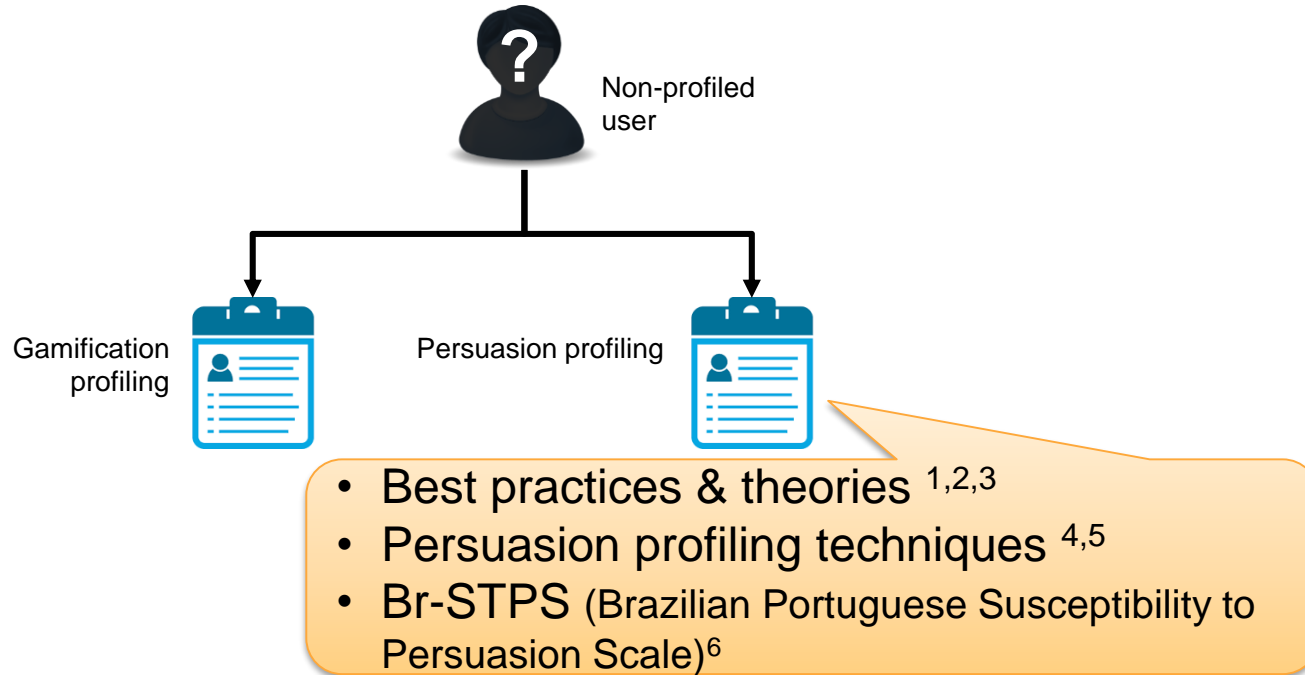
2 YEE, N. Motivations for play in online games. *Cyber Psychology & behavior*, Mary Ann Liebert, Inc, v. 9, n. 6, p. 772–775, 2006

3 HAMARI, J.; KOIVISTO, J.; SARSA, H. Does Gamification Work? – A Literature Review of Empirical Studies on Gamification. In: 47th Hawaii Intern. Conference on System Sciences. IEEE, 2014. p. 3025–3034.

4 ANDRADE, F. R. H.; MARQUES, L. B.; BITTENCOURT, I. I.; ISOTANI, S. QPJ - BR : Questionário para Identificação de Perfis de Jogadores para o Português - Brasileiro. *CBIE*, p. 637–646, 2016.

**5 BORGES, S. S. et al. A Link Between Worlds: Towards a Conceptual Framework for Bridging Player and Learner Roles in Gamified Collaborative Learning Contexts. In: KOCH, F. et al. (Eds.). . *Advances in Social Computing and Digital Education*. Cham: Springer International Publishing, 2016. v. 677p. 19–34.**

# Approach to personalized inner loop design



1 FOGG, B. J. Persuasive Technology: Using Computers to Change What We Think and Do (Interactive Technologies). 1. ed. Morgan Kaufmann, 2002.

2 CIALDINI, R. B. Influence: The Psychology of Persuasion. HarperCollins, 1993.

3 KAPTEIN, M.; MARKOPOULOS, P.; AARTS, E. Can You Be Persuaded? Individual Differences in Susceptibility to Persuasion. In: LNCS. v. 5726, PART 1, p. 115–118, 2009.

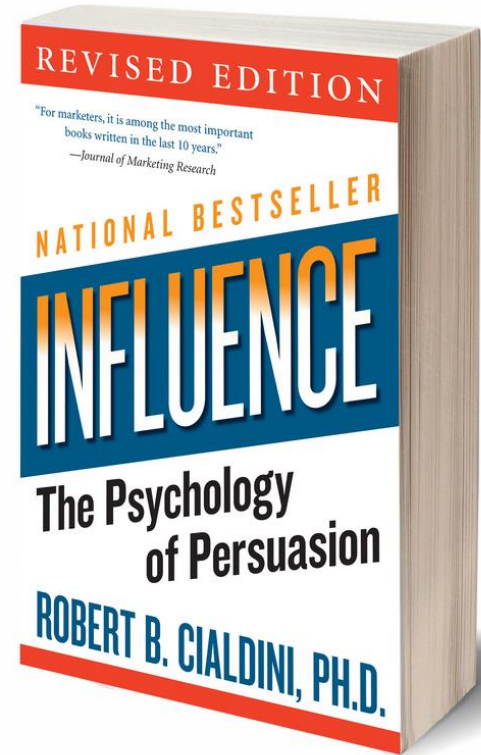
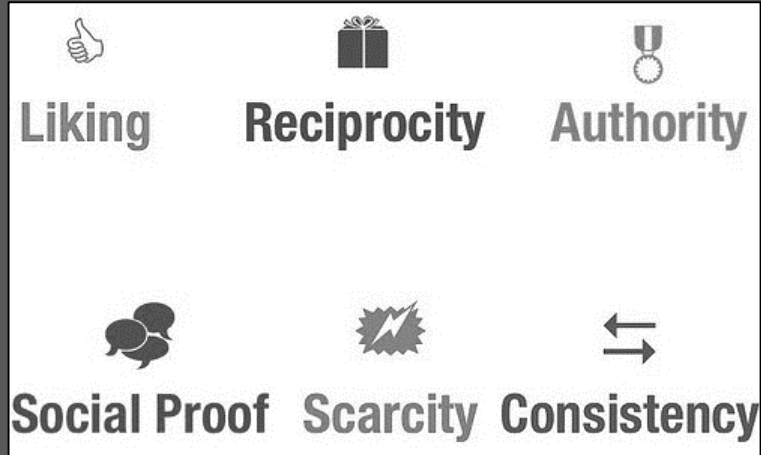
4 KAPTEIN, M. et al. Personalizing persuasive technologies: Explicit and implicit personalization using persuasion profiles. Inter. Journal of Human Computer Studies, v. 77, p. 38–51, 2015.

5 KAPTEIN, M. et al. Adaptive Persuasive Systems. ACM Transactions on Interactive Intelligent Systems, v. 2, n. 2, p. 1–25, 1 jun. 2012.

6 BORGES, S. S.; DURELLI, V. H. S.; REIS, H. M.; BITTENCOURT, I. MIZOGUCHI, R.; ISOTANI, S. Brazilian Portuguese Cross-Cultural Adaptation and Validation of the Susceptibility Persuasion Scale ( Br-STPS ). In: IEEE 17th International Conference on Advanced Learning Technologies. Timisoara: IEEE Computer Society, 2017. p. 1–2.

# Susceptibility to Persuasion Scale<sup>1</sup>

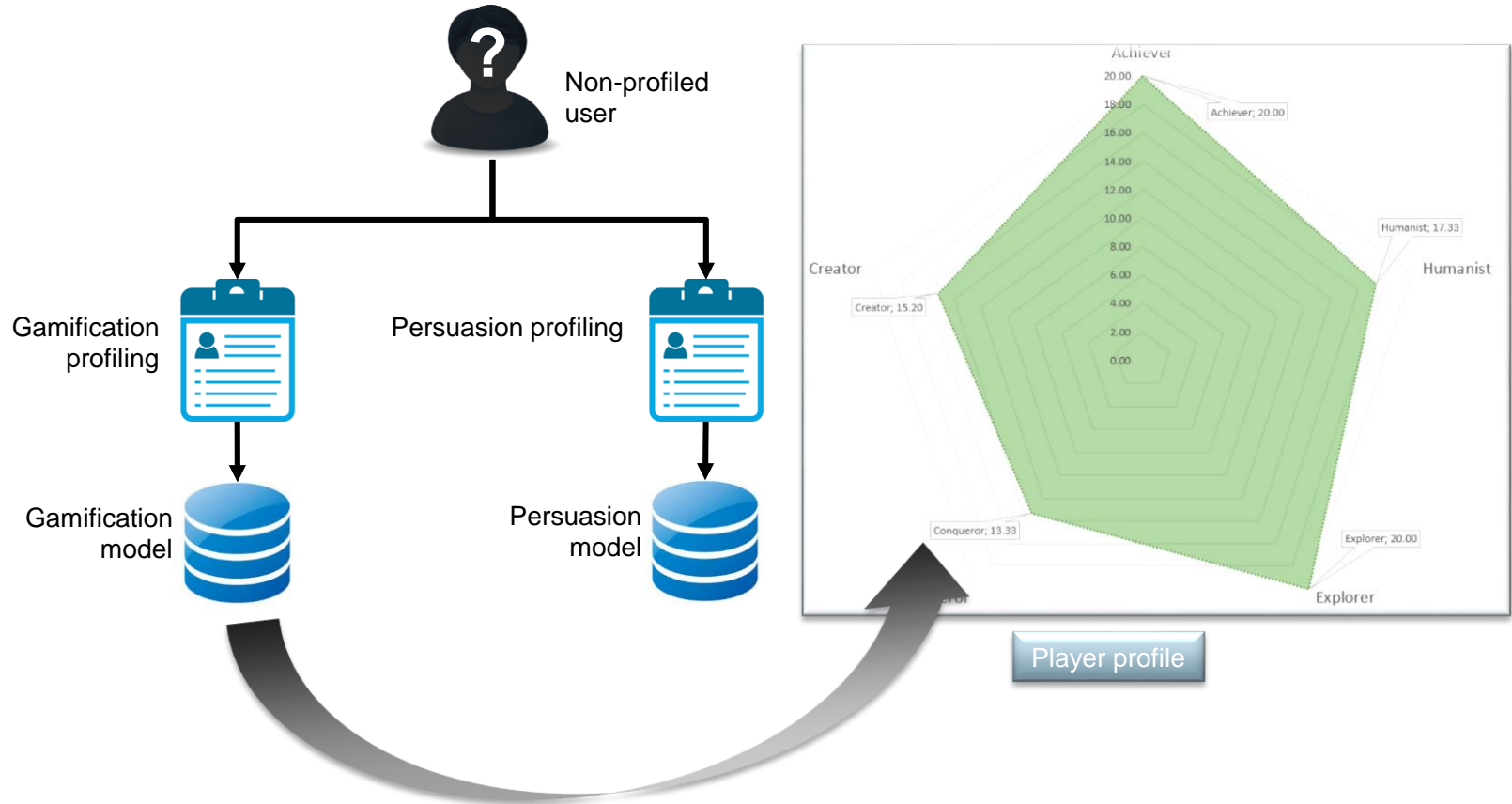
## Influence Principles<sup>2</sup>



<sup>1</sup> KAPTEIN, M. et al. Adaptive Persuasive Systems. ACM Transactions on Interactive Intelligent Systems, v. 2, n. 2, p. 1–25, 1 jun. 2012.

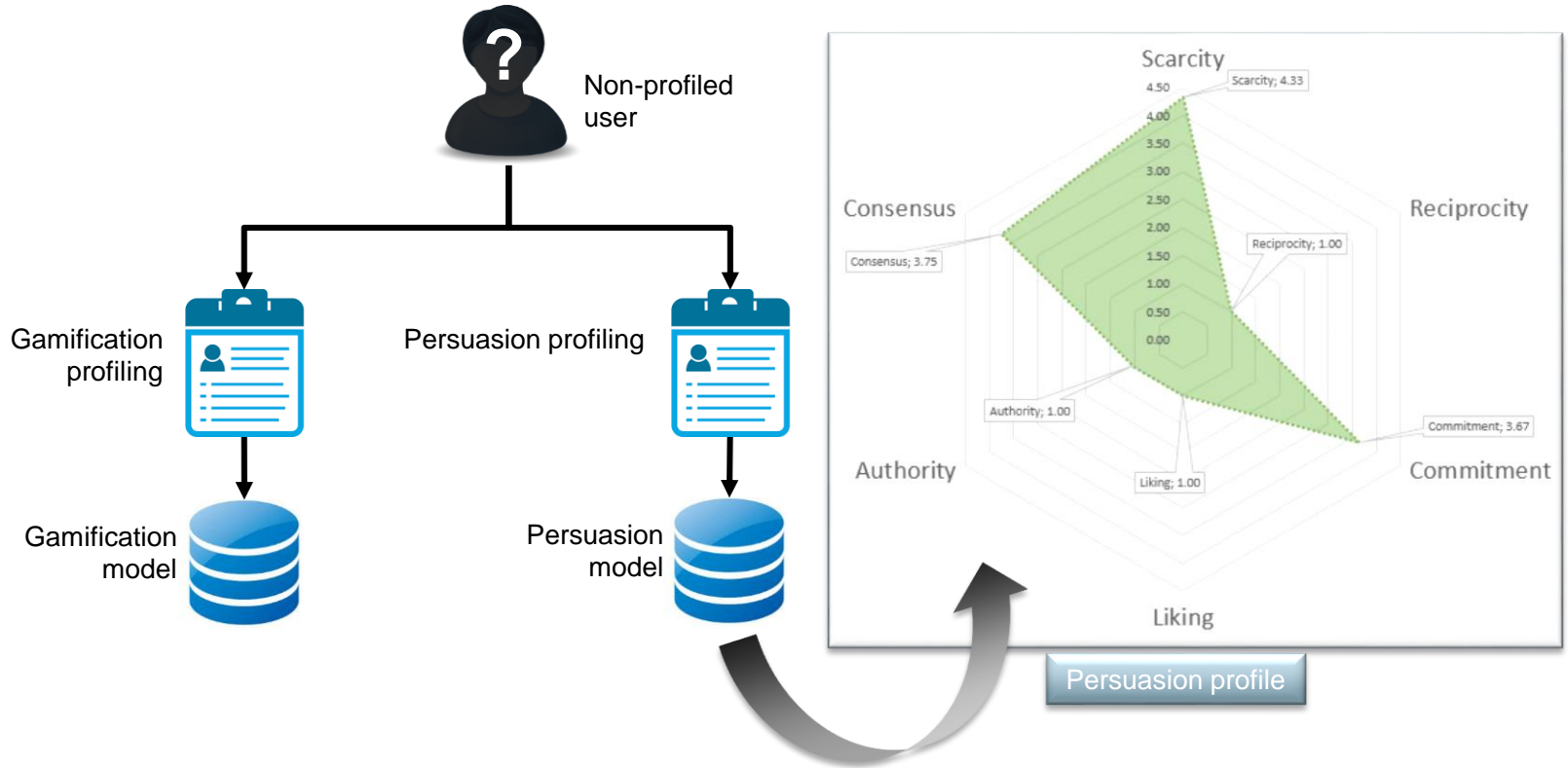
<sup>2</sup> CIALDINI, R. B. Influence: The Psychology of Persuasion. HarperCollins, 1993.

# Approach to personalized inner loop design

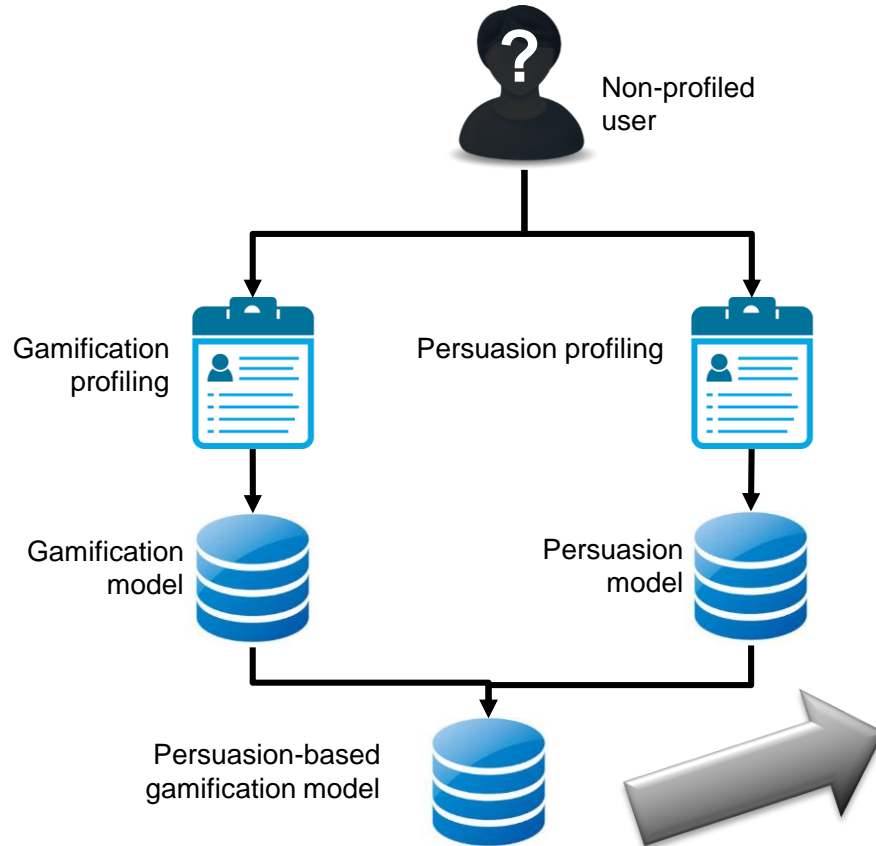




# Approach to personalized inner loop design



# Approach to personalized inner loop design



Is there a way to **tailor** influence principles to different player roles?

# Tailoring influence principles to different player roles<sup>1</sup>

Best and worst influence principles, from left to right, the principles are listed according to the highest path coefficient ( $\beta$ ) measured<sup>1</sup>.

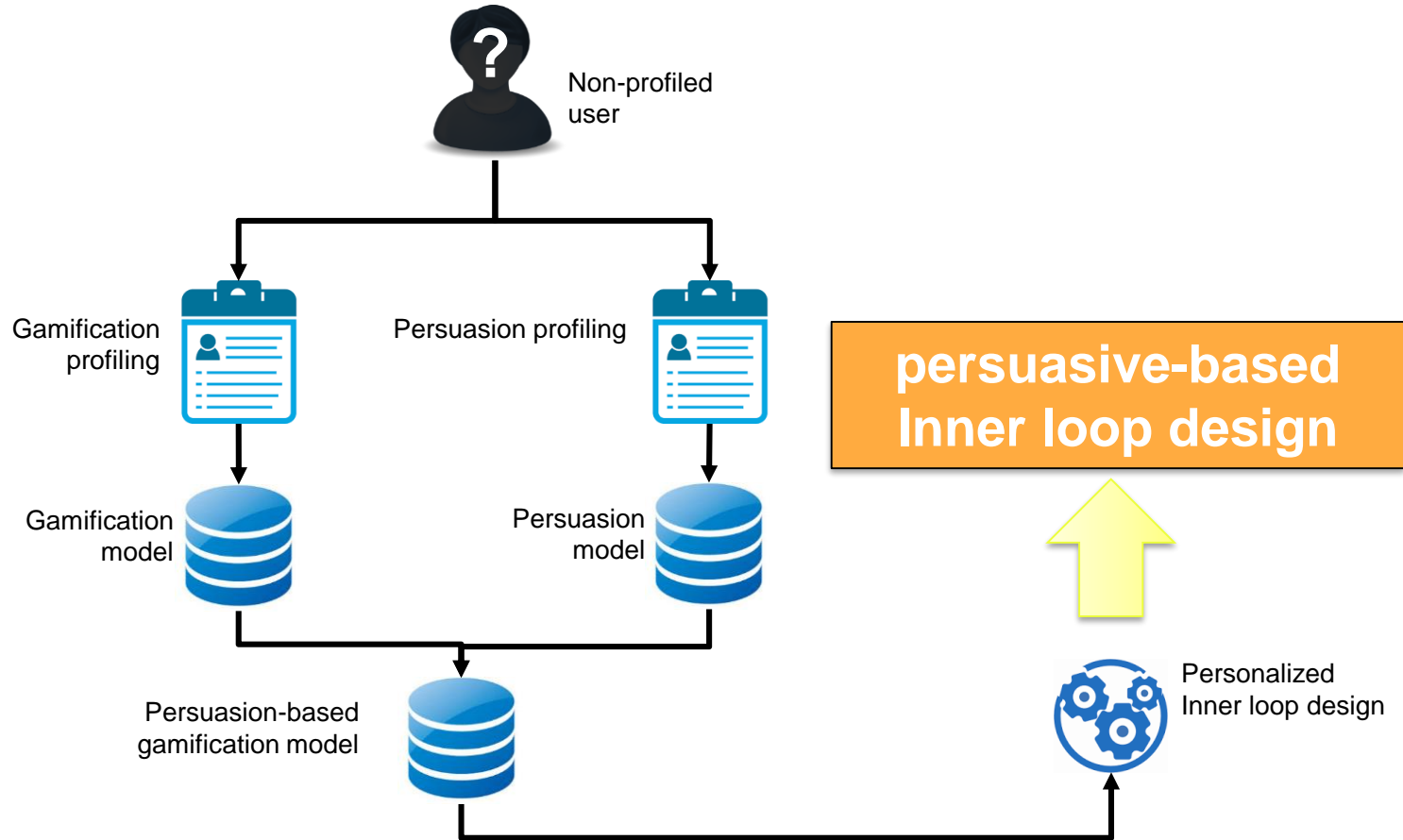
| Player Role | Influence Principle                              |                     |
|-------------|--|---------------------|
| Achiever    | <i>Best</i><br>Reciprocity, Commitment, Scarcity | <i>Worst</i><br>N/A |
| Creator     | Consensus, Scarcity, Commitment,                 | Authority           |
| Conqueror   | Scarcity, Consensus, Liking, Commitment          | N/A                 |
| Explorer    | Scarcity, Commitment                             | Authority           |
| Humanist    | Consensus, Reciprocity, Liking                   | Authority           |

1 BORGES, S. S.; DURELLI, V. H. S.; REIS, H. M.; BITTENCOURT, I. I. MIZOGUCHI, R.; ISOTANI, S. Selecting Effective Influence Principles for Tailoring Gamification-Based Strategies to Player Roles. In: XXVIII Simpósio Brasileiro de Informática na Educação. 2017. p. 234–243 (accepted for publication).

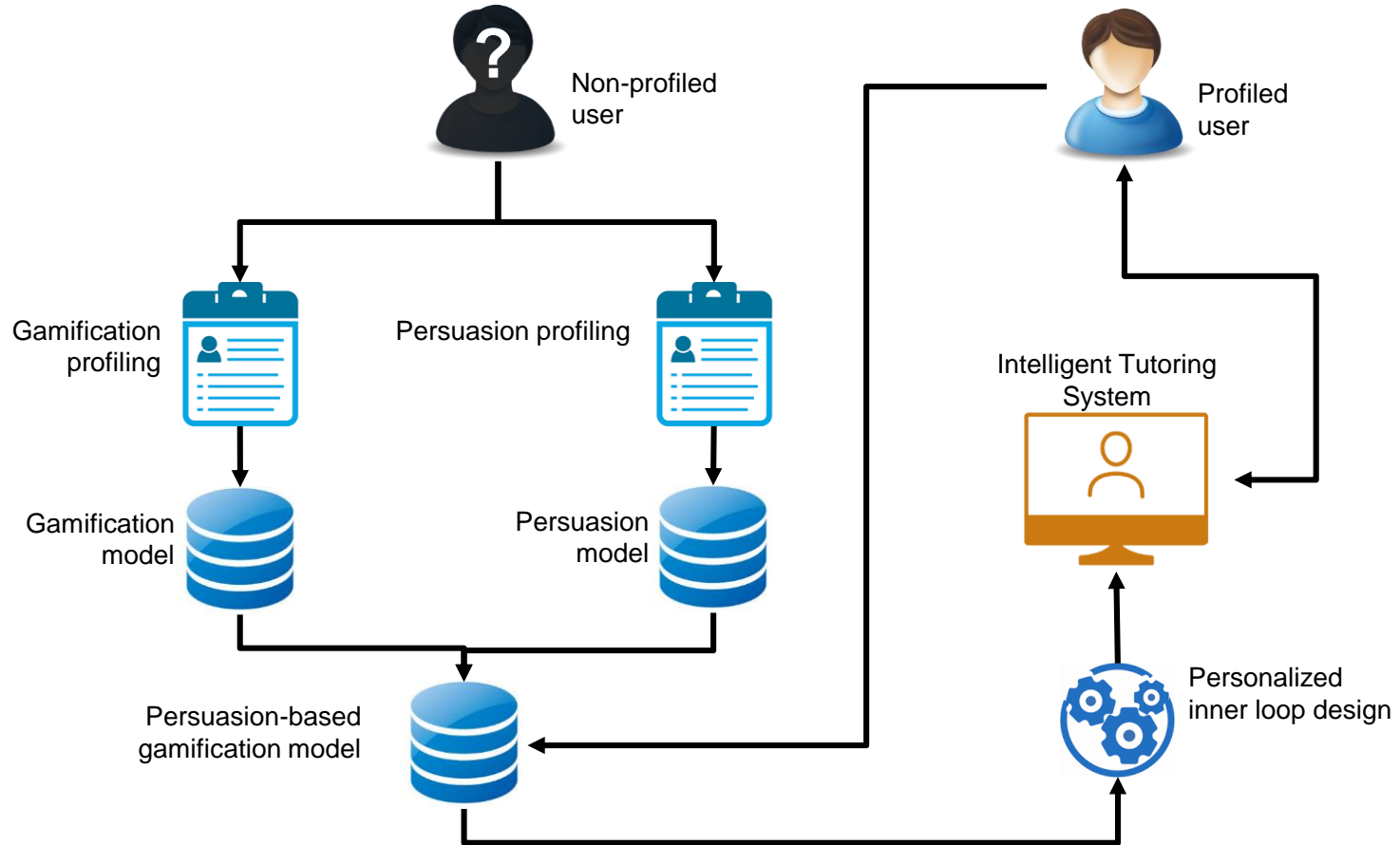
2 ANDRADE, F. R. H.; MARQUES, L. B.; BITTENCOURT, I. I.; ISOTANI, S. QPJ - BR : Questionário para Identificação de Perfis de Jogadores para o Português - Brasileiro. CBIE, p. 637–646, 2016.

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# Approach to personalized inner loop design



# Approach to personalized inner loop design





THANK YOU!



# Intelligent Tutoring System: The importance of the Inner Loop

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# Approach to personalized inner loop design

