Intelligent Tutoring System: The importance of the Inner Loop

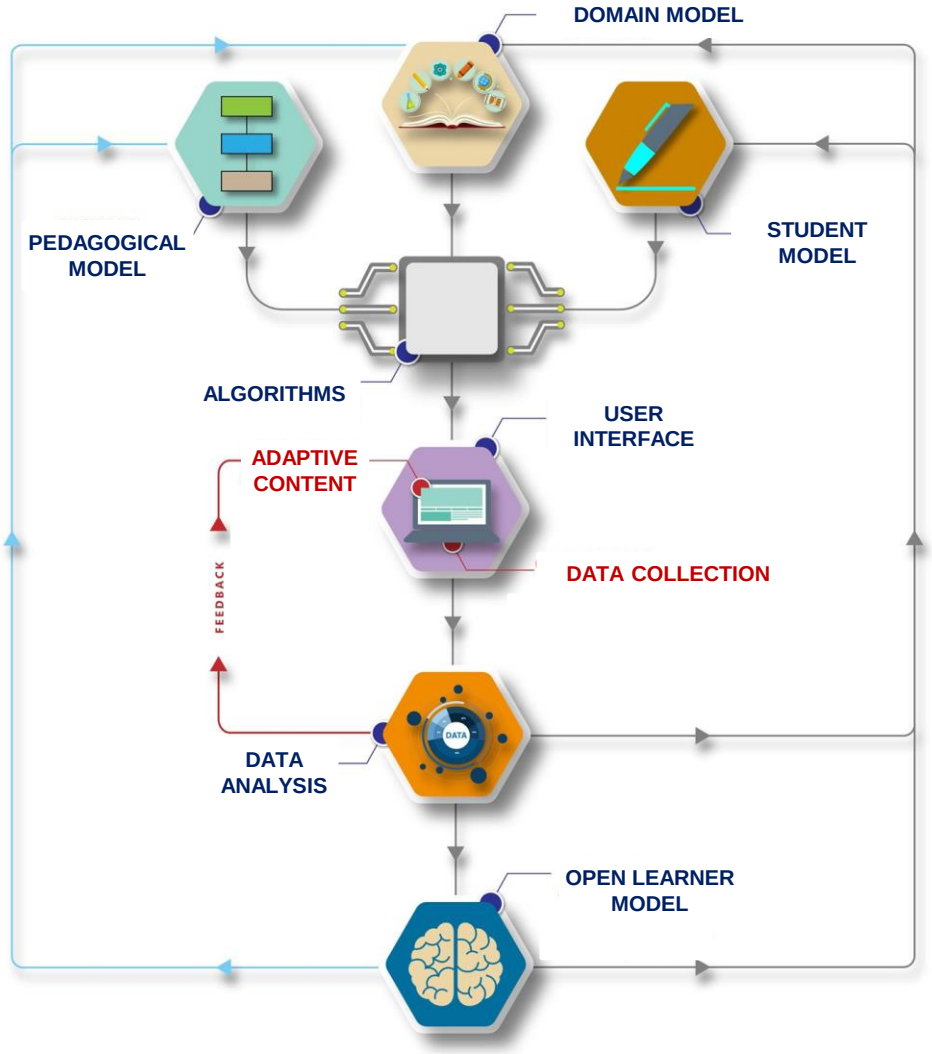
Prof. Seiji Isotani
University of Sao Paulo
sisotani@icmc.usp.br

Intelligent Tutoring Systems (ITS)

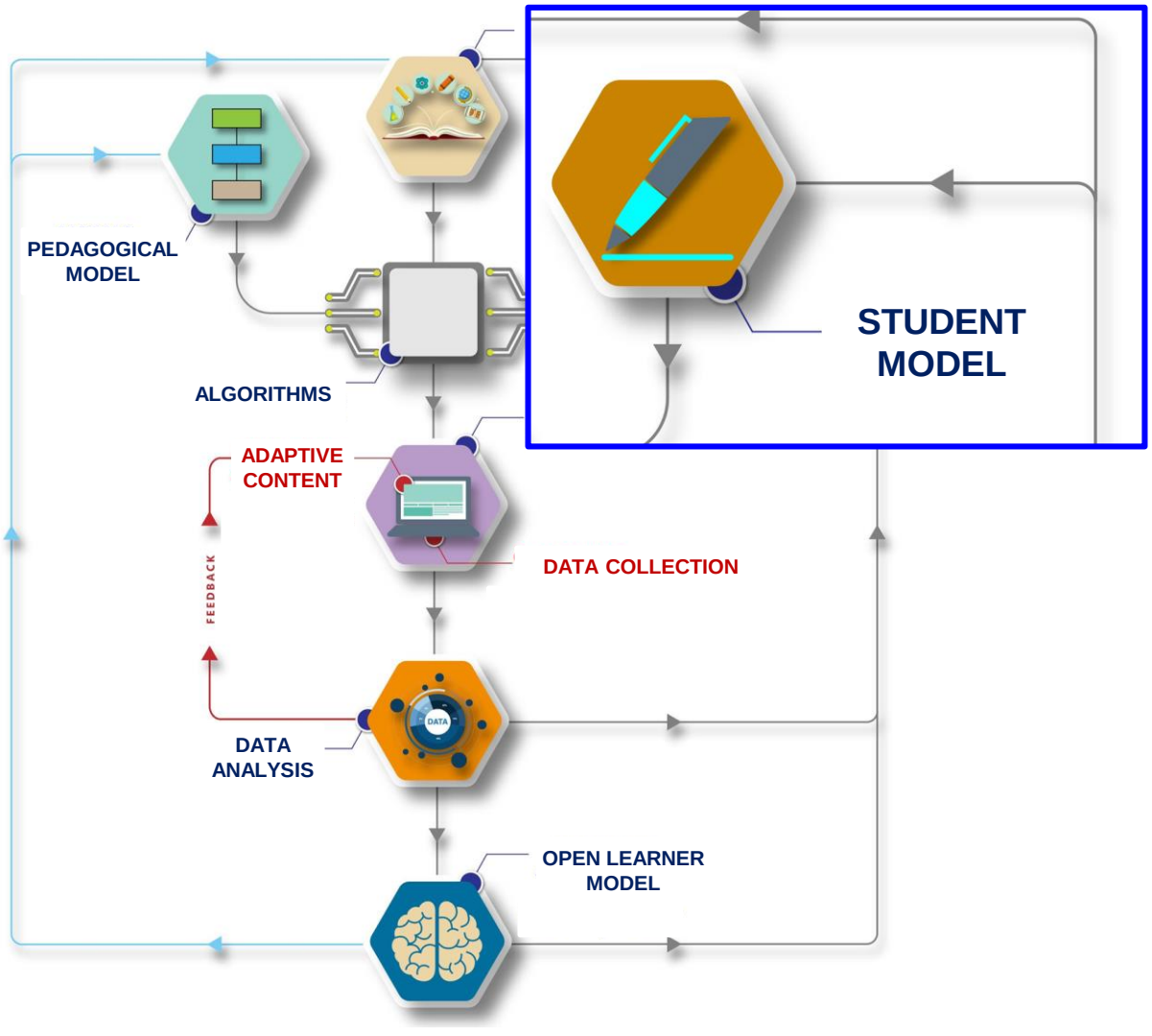
A Definition

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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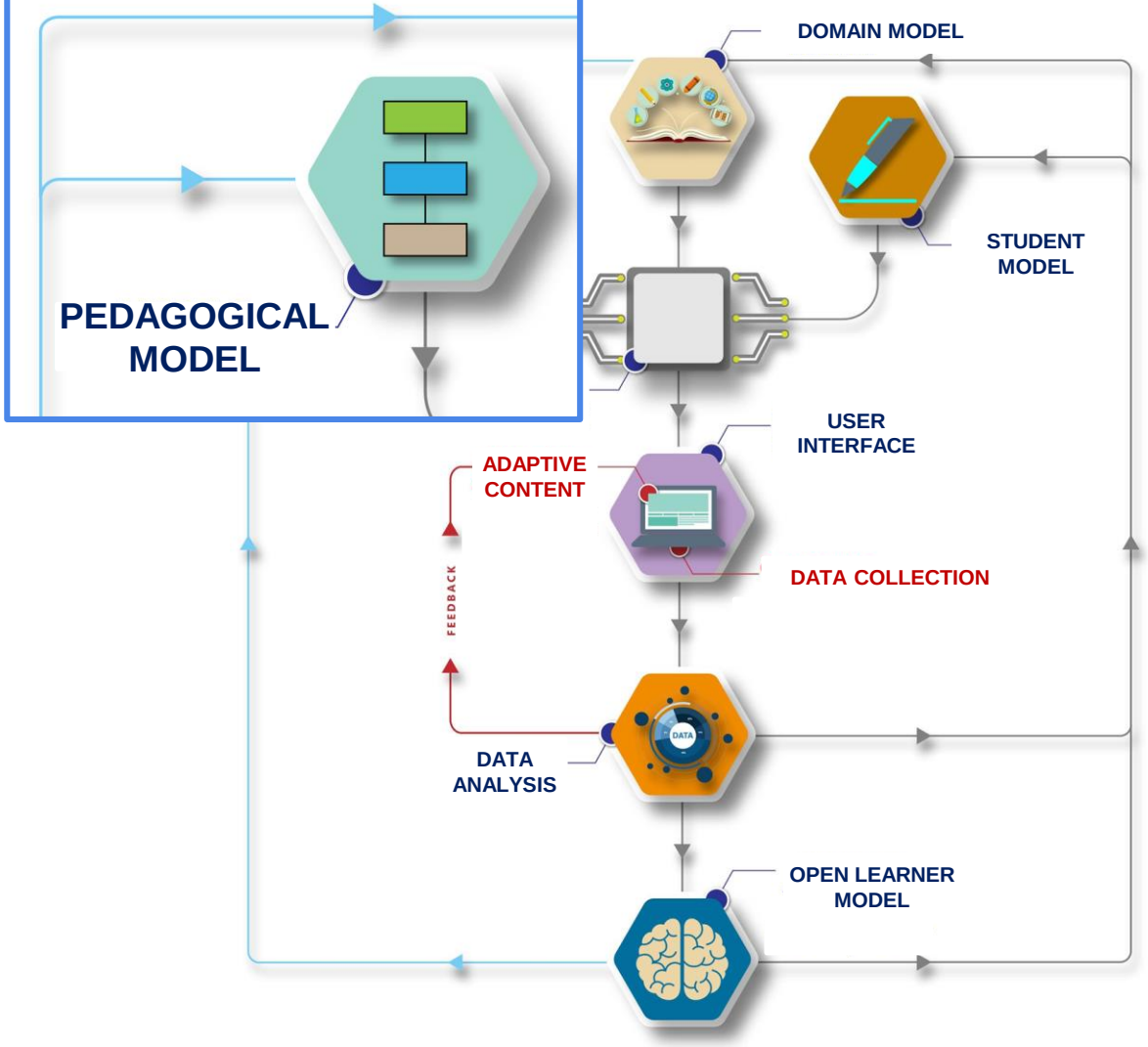

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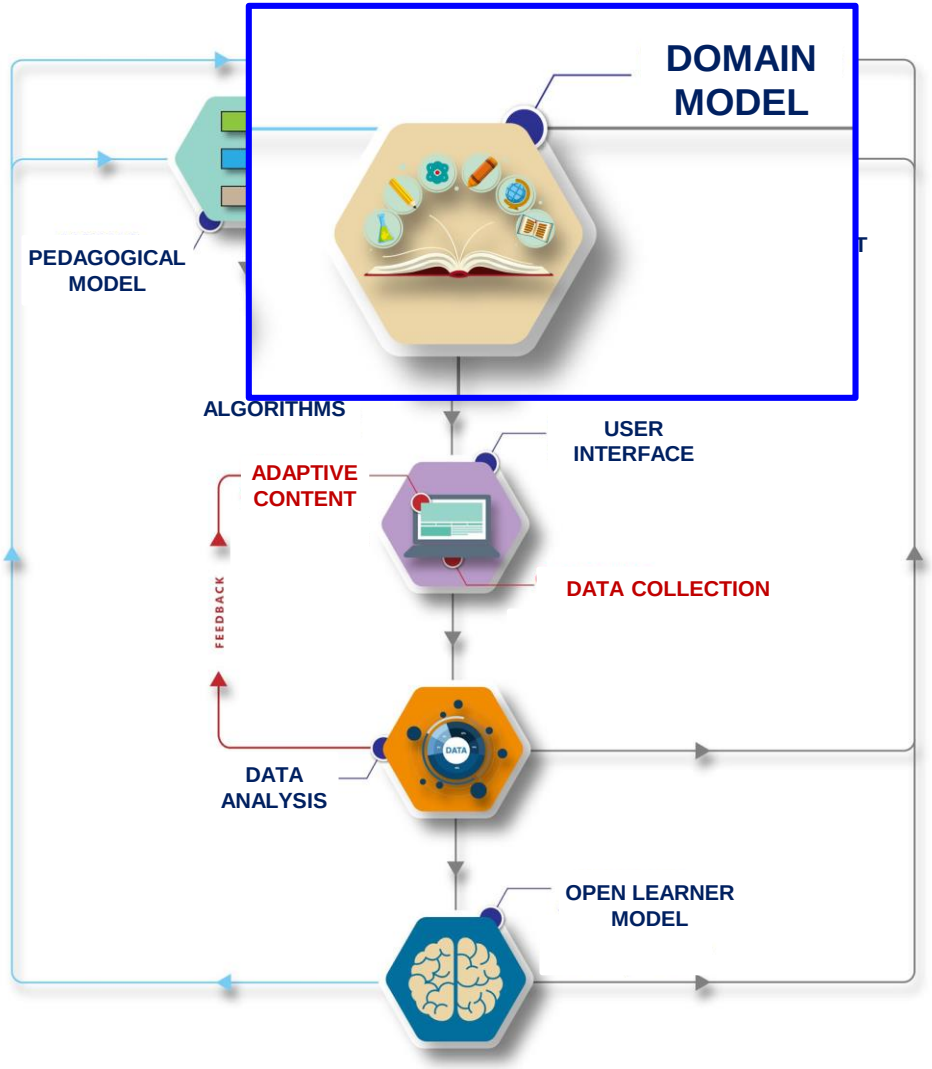

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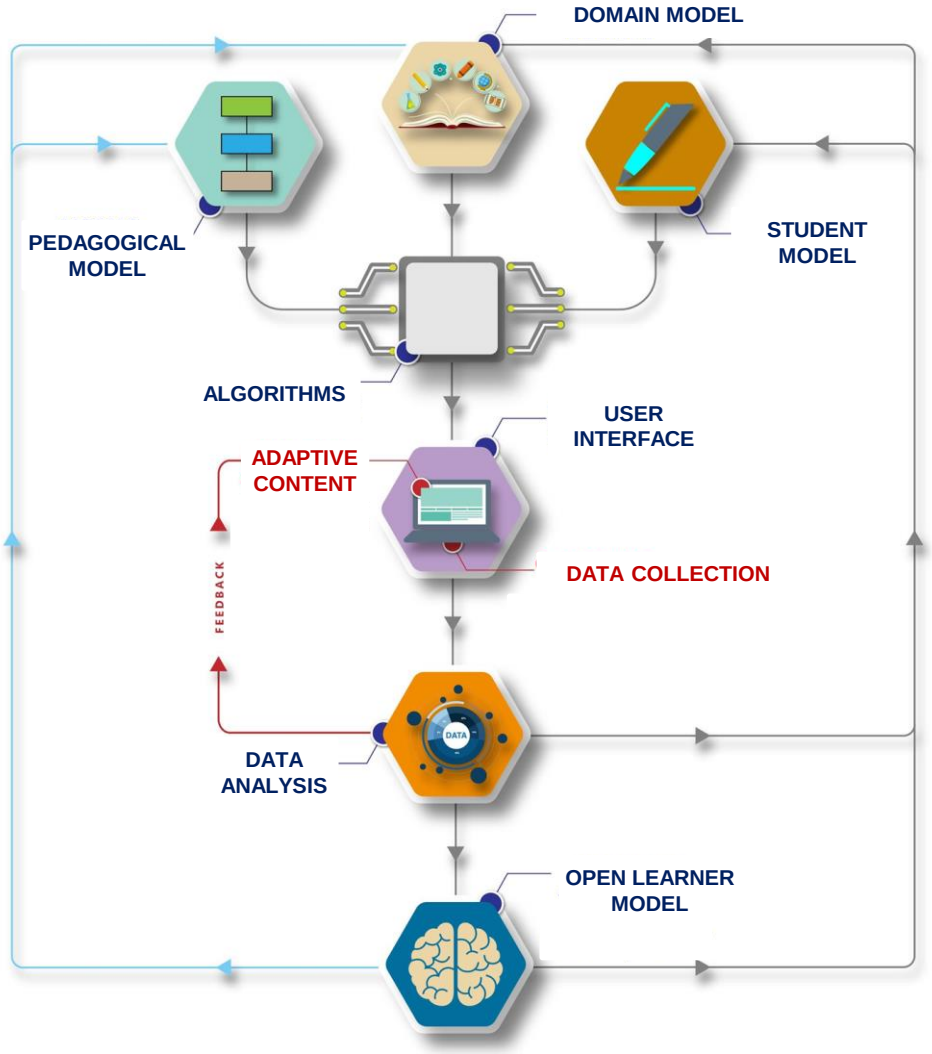

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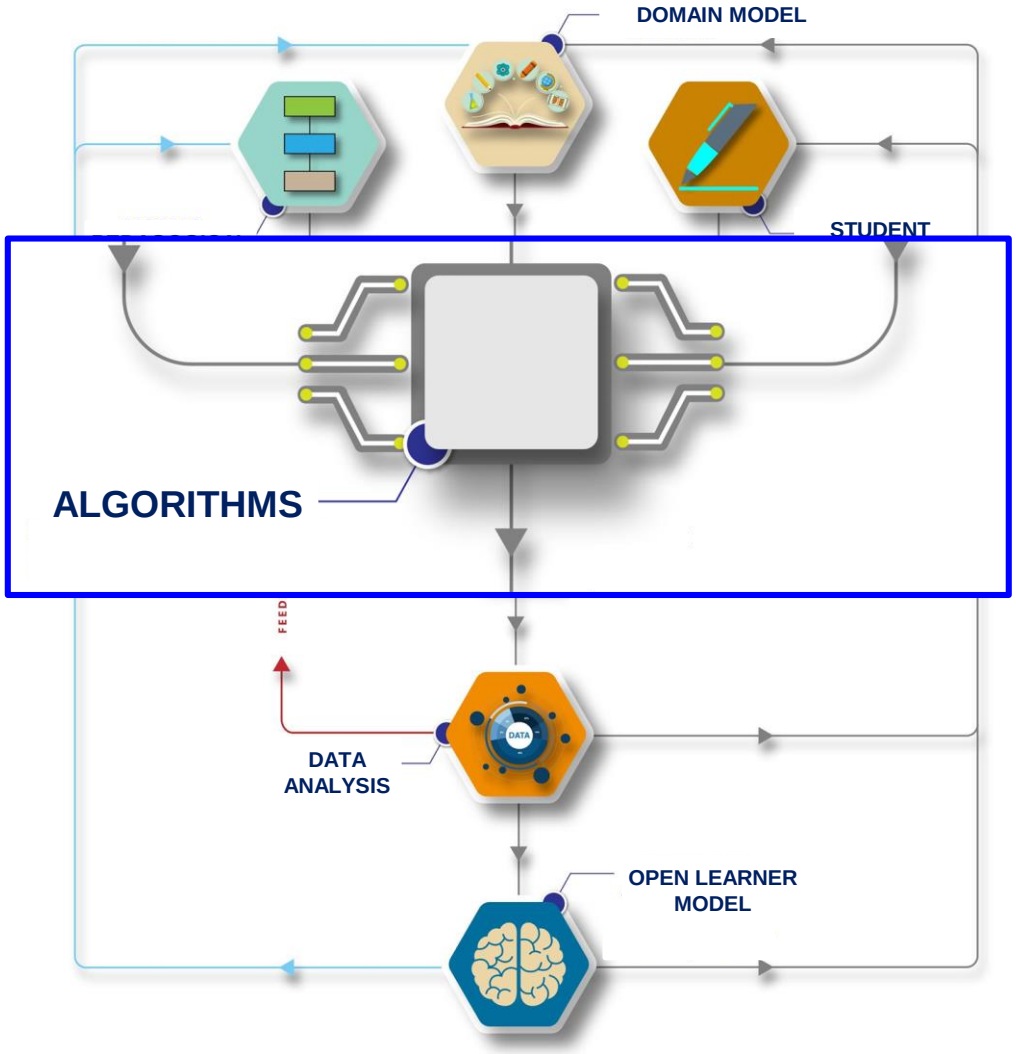

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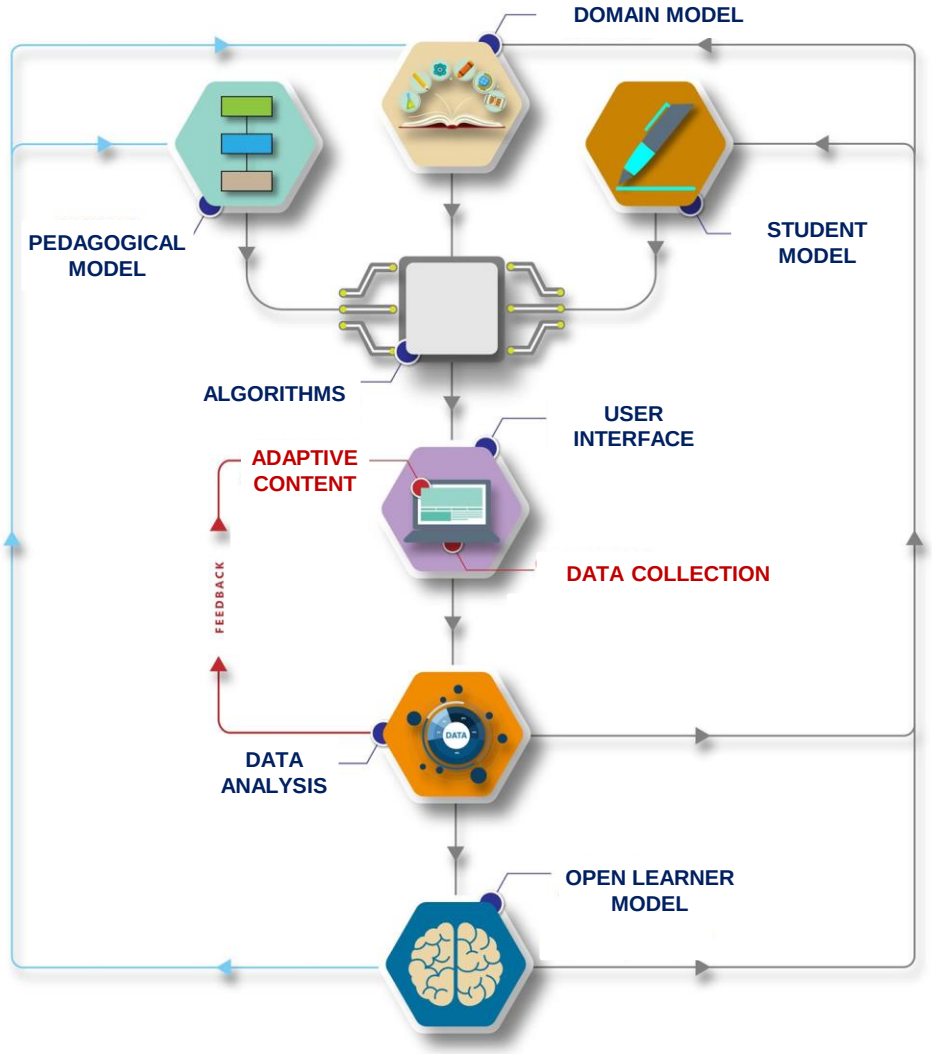
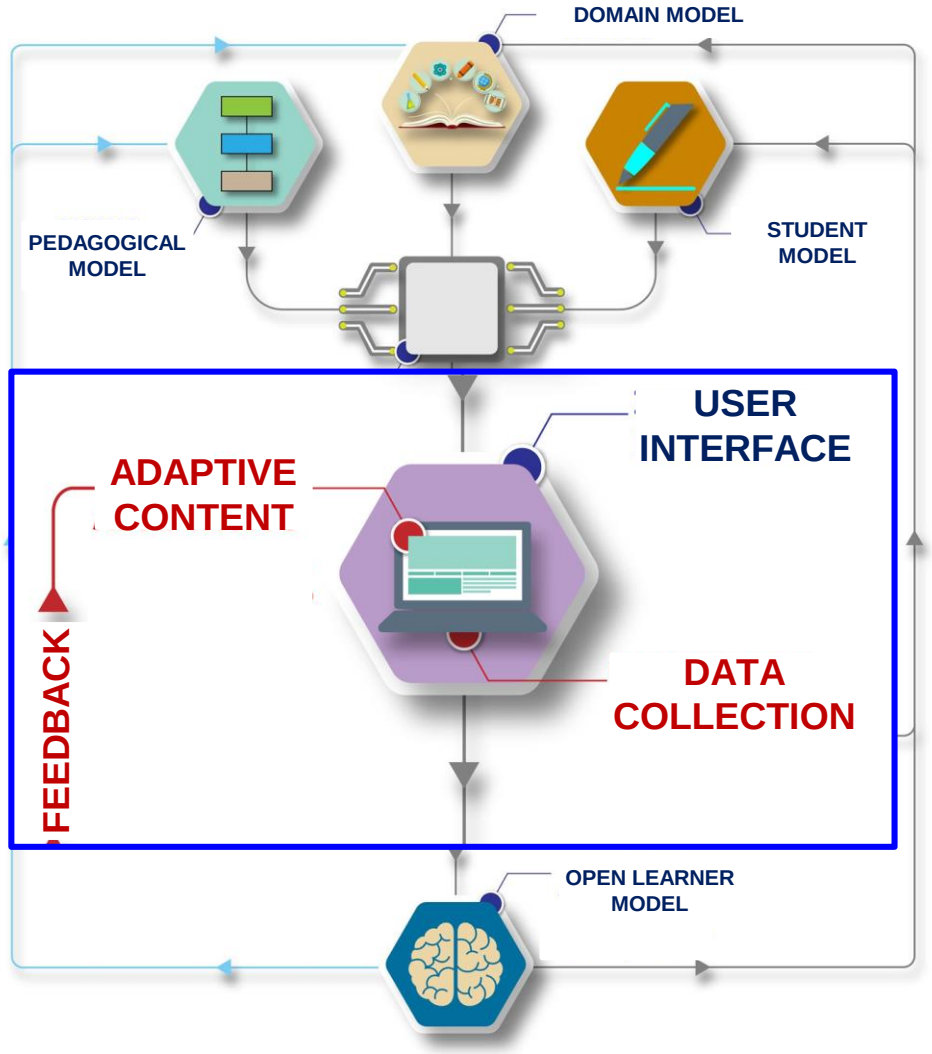


ITS ARCHITECTURE



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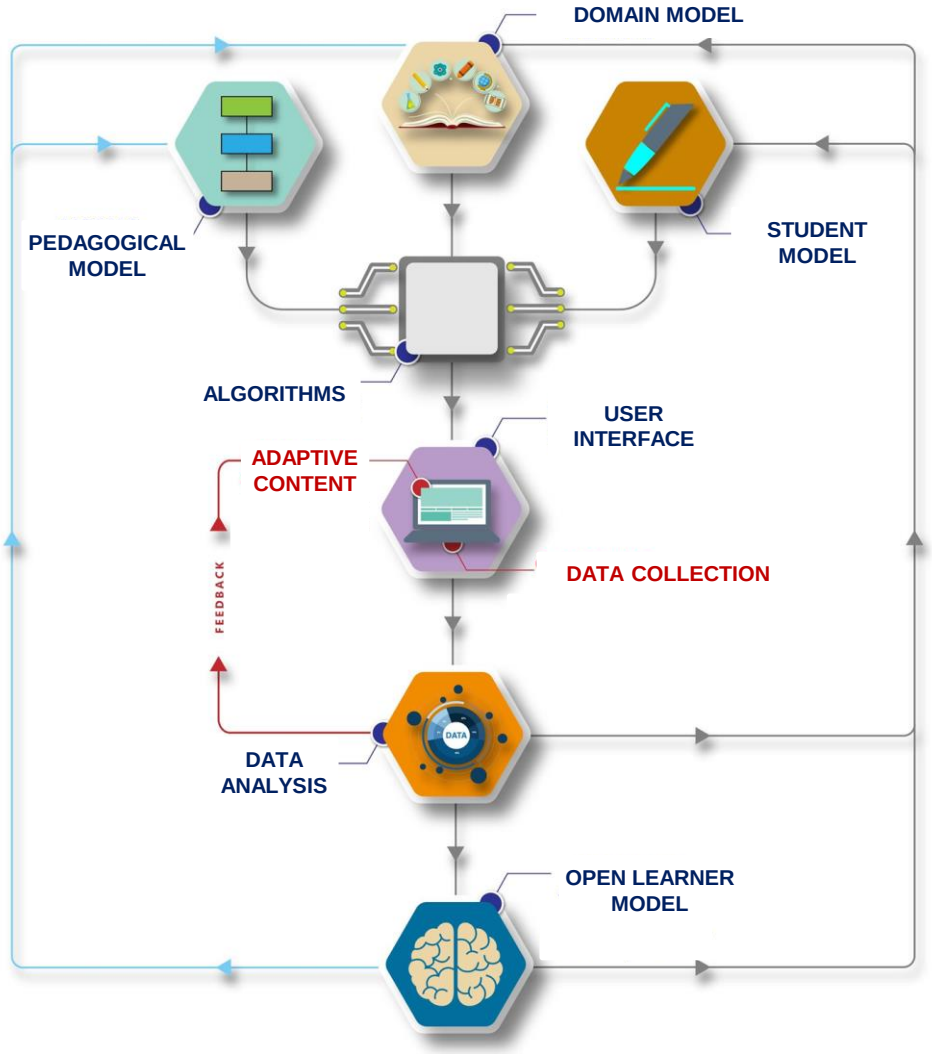

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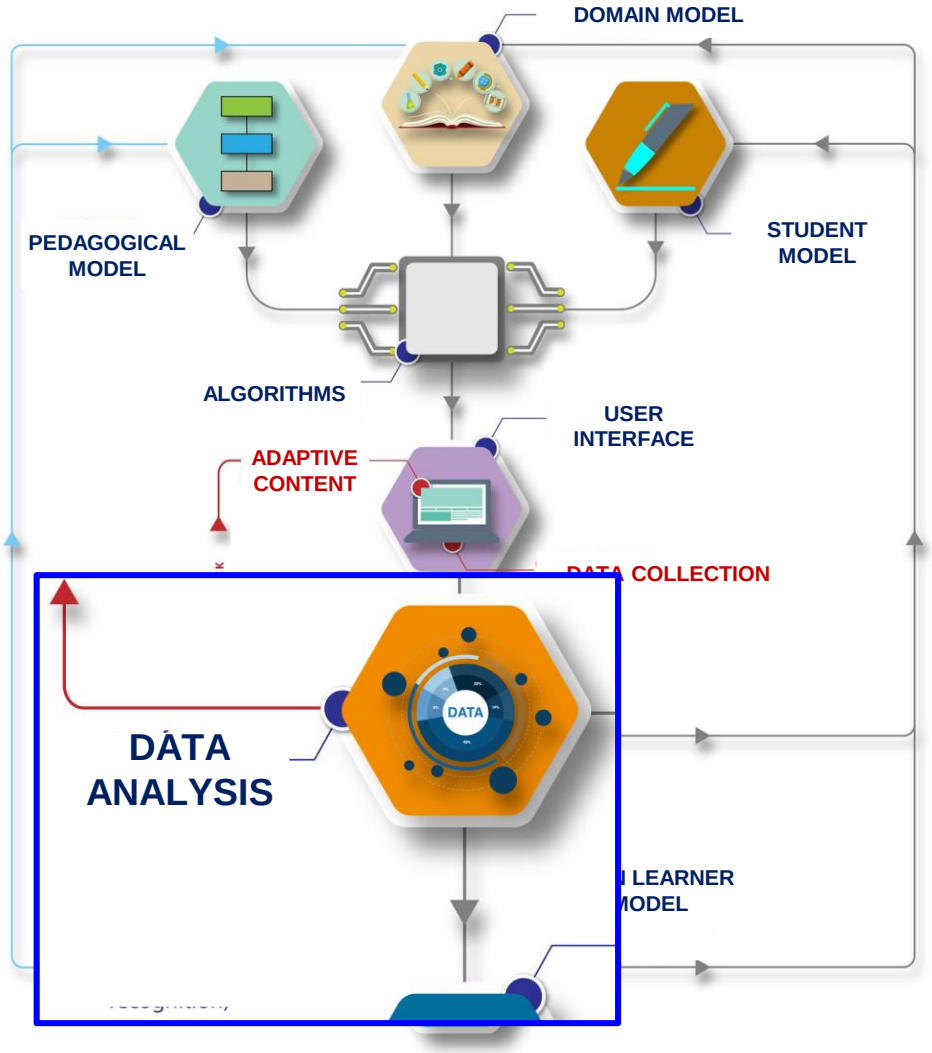

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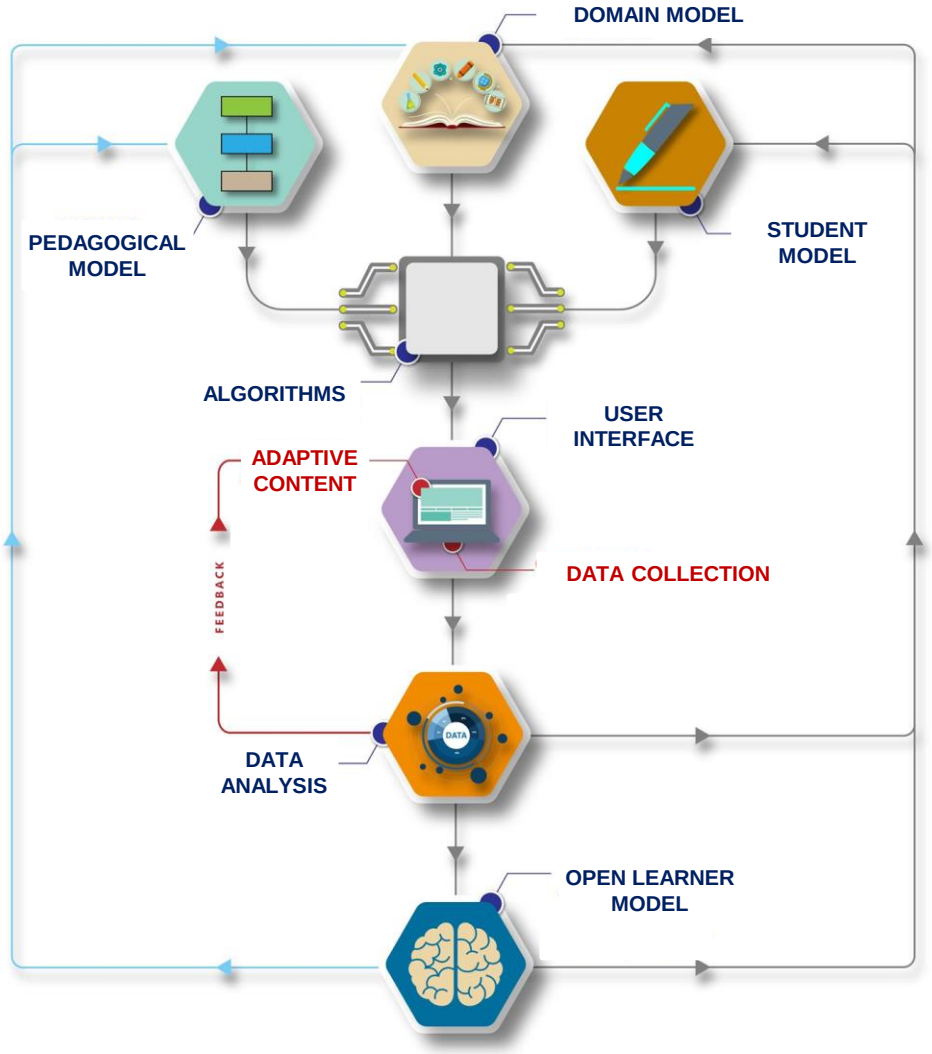

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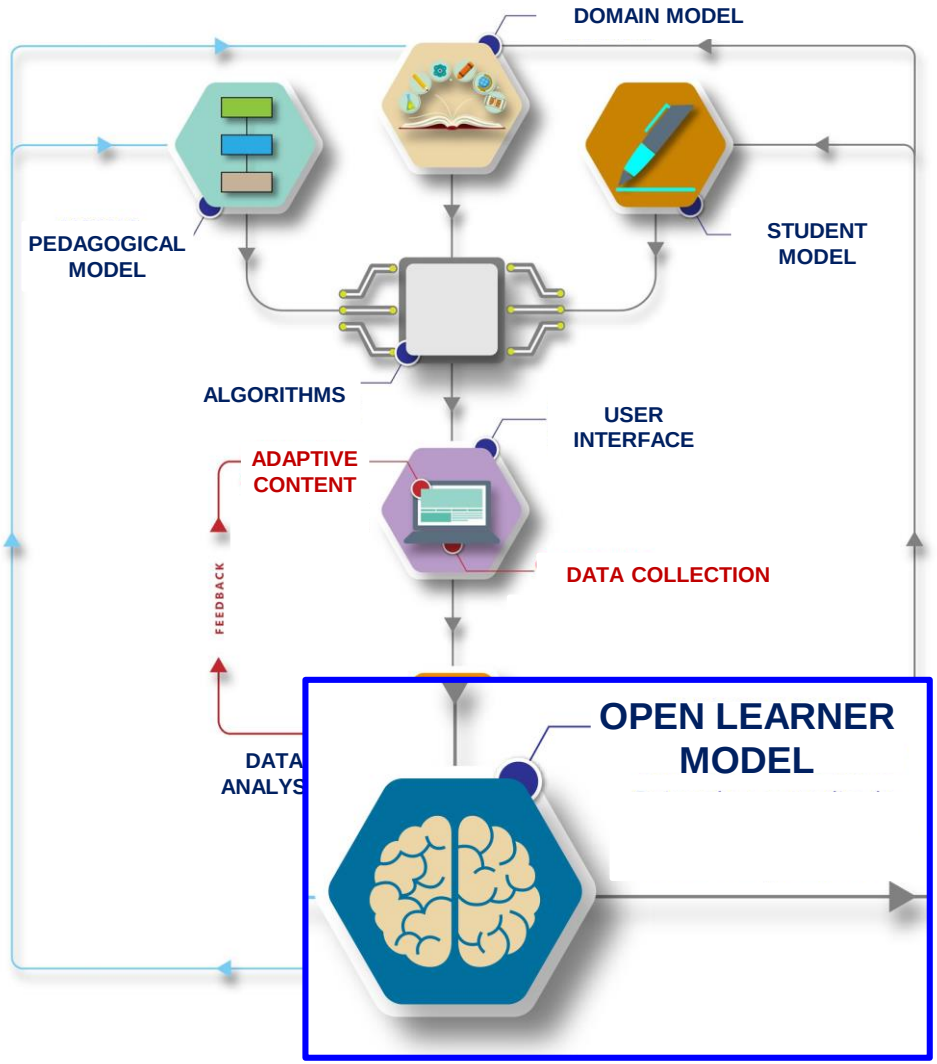
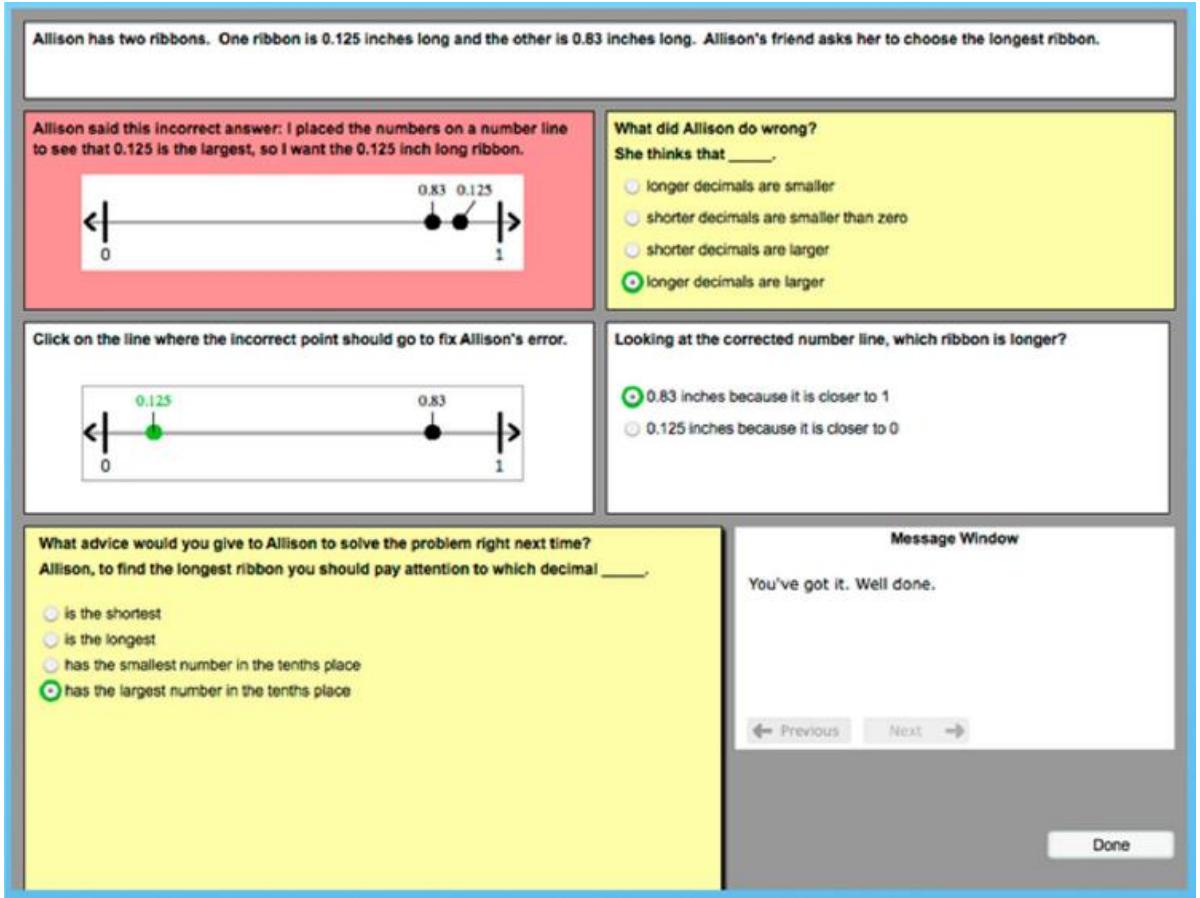


Examples of ITS

Example of Intelligent Tutoring Systems

Mathematics

Learning from Errors

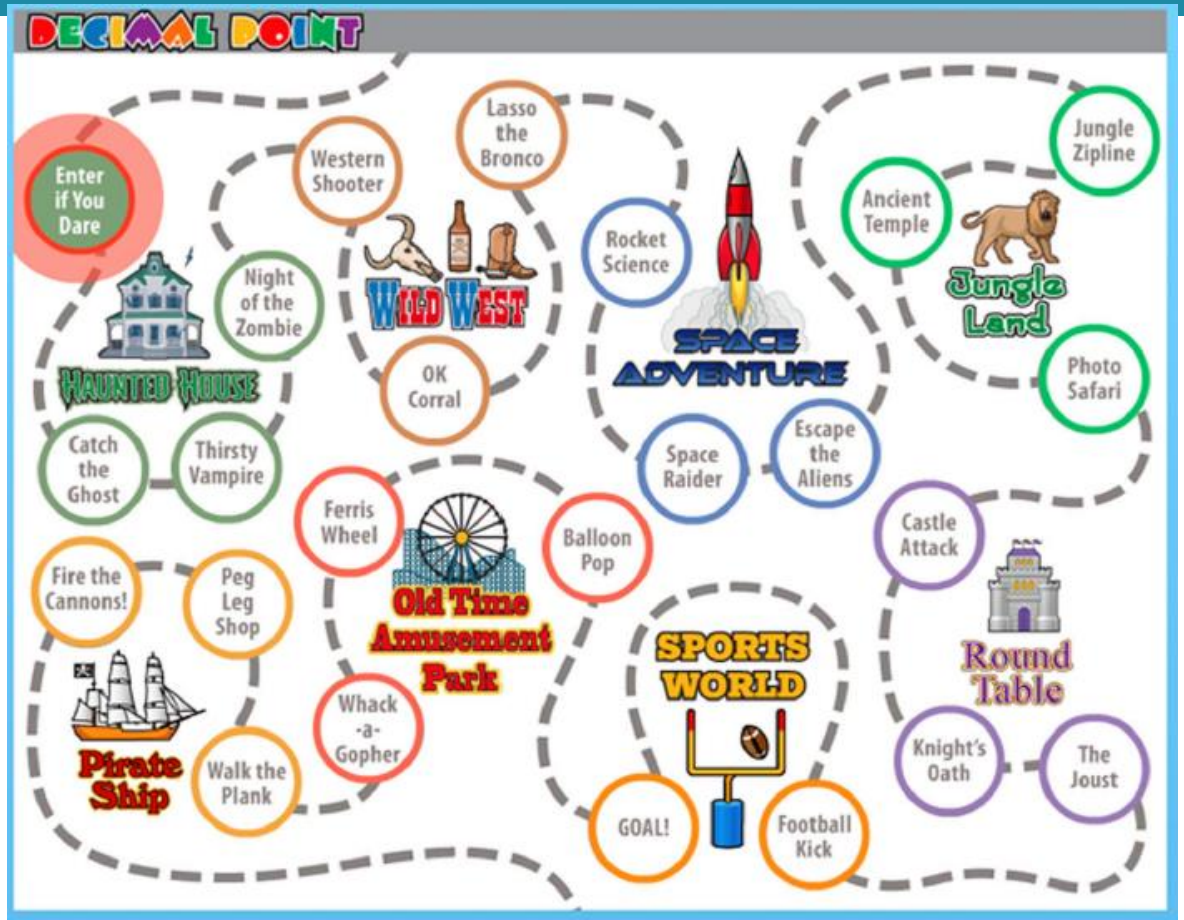


Isotani et al. (2011)

Example of Intelligent Tutoring Systems

Mathematics

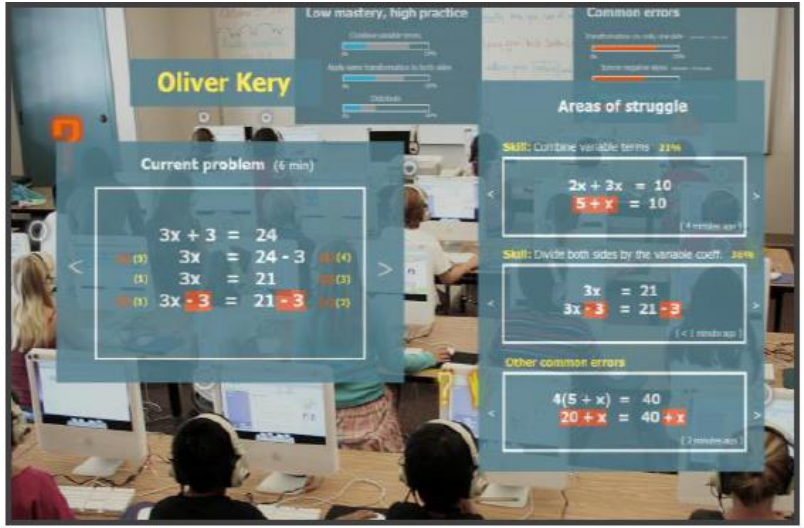
Game-based learning



Aleven et al. (2016)

Example of Intelligent Tutoring Systems

Mathematics - Virtual reality



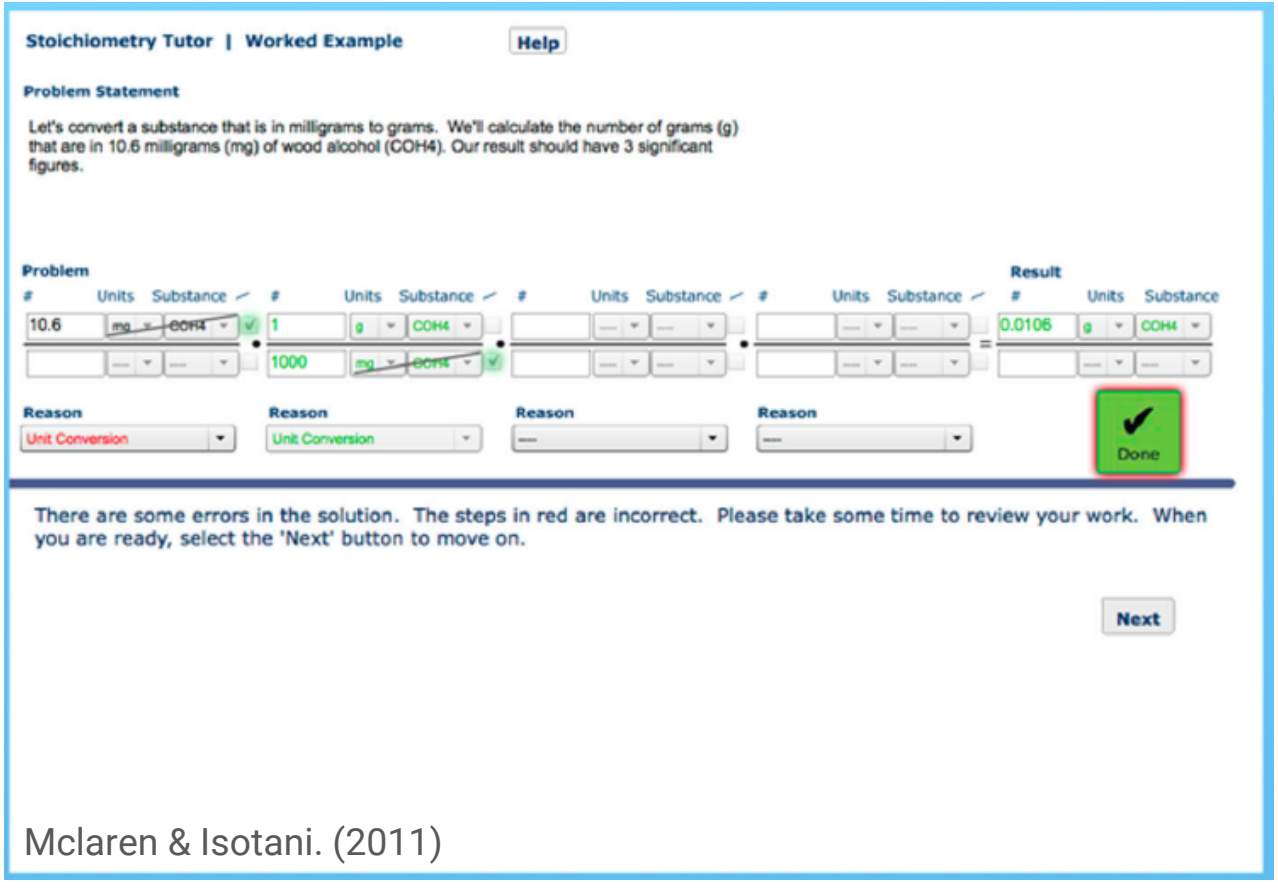
https://youtu.be/Dexjdmfv2c4?t=53

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



Mclaren & Isotani. (2011)

Example of Intelligent Tutoring Systems

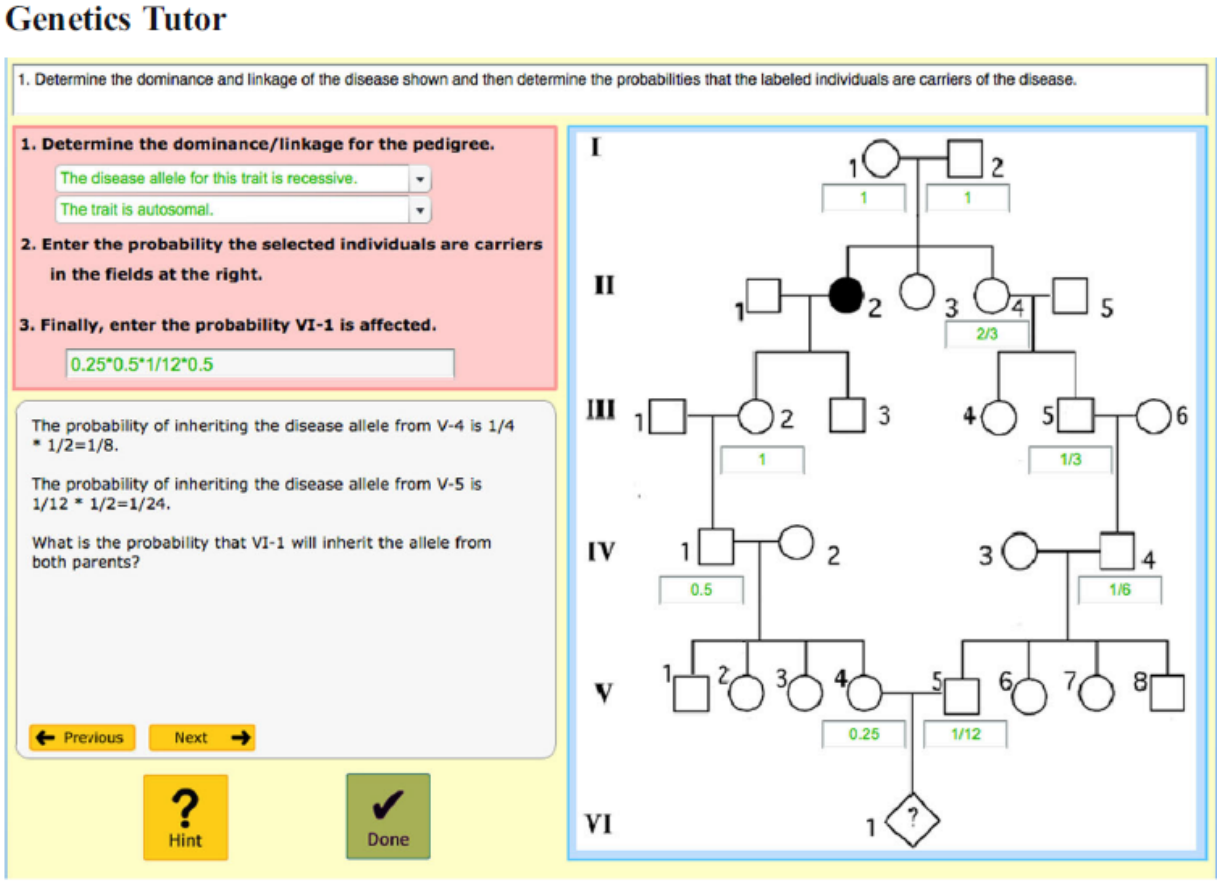
Generic

Gamification-based ITS

Tenorio, Bittencourt, Isotani et al. (2016)

Example of Intelligent Tutoring Systems

Genetics

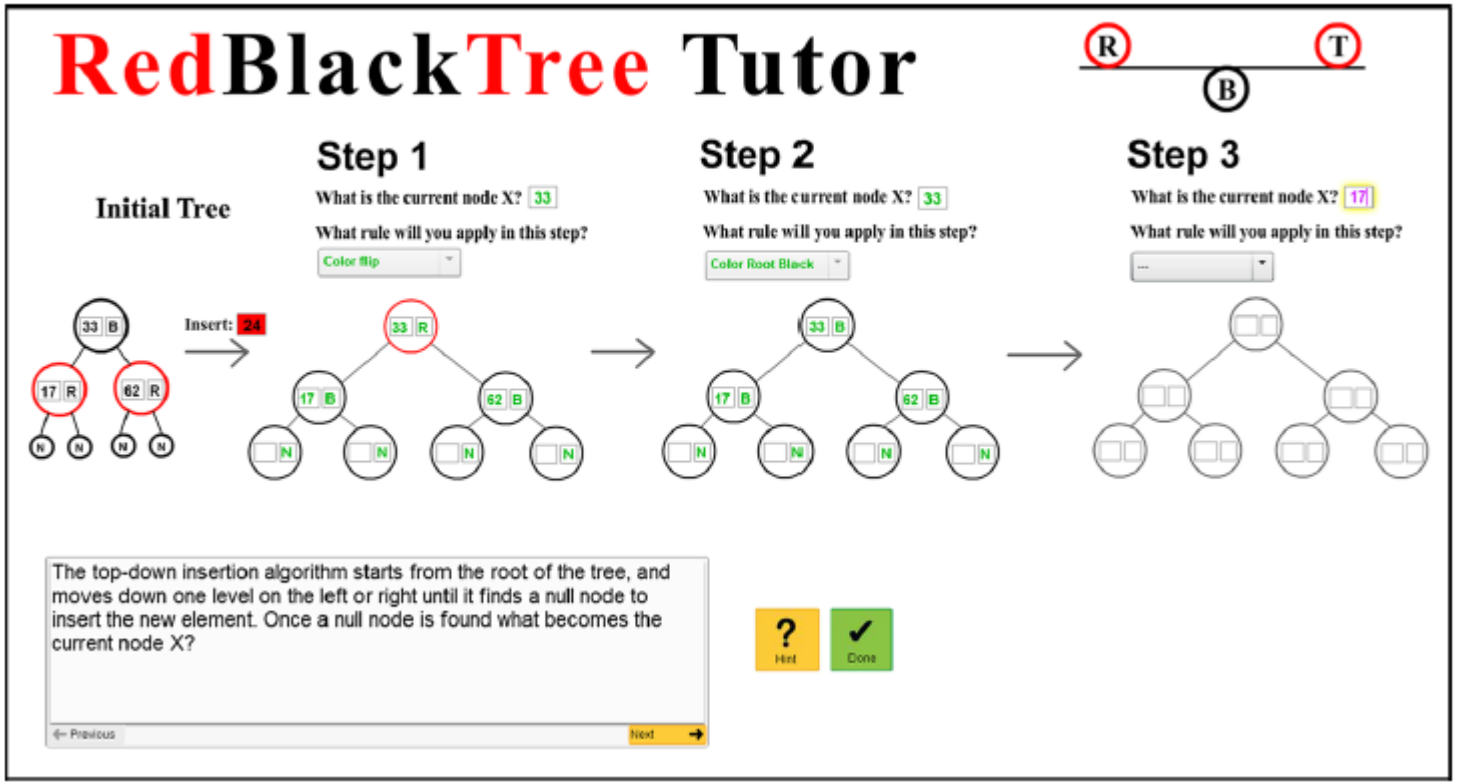


Aleven et al. (2016)

Example of Intelligent Tutoring Systems

Computer Science

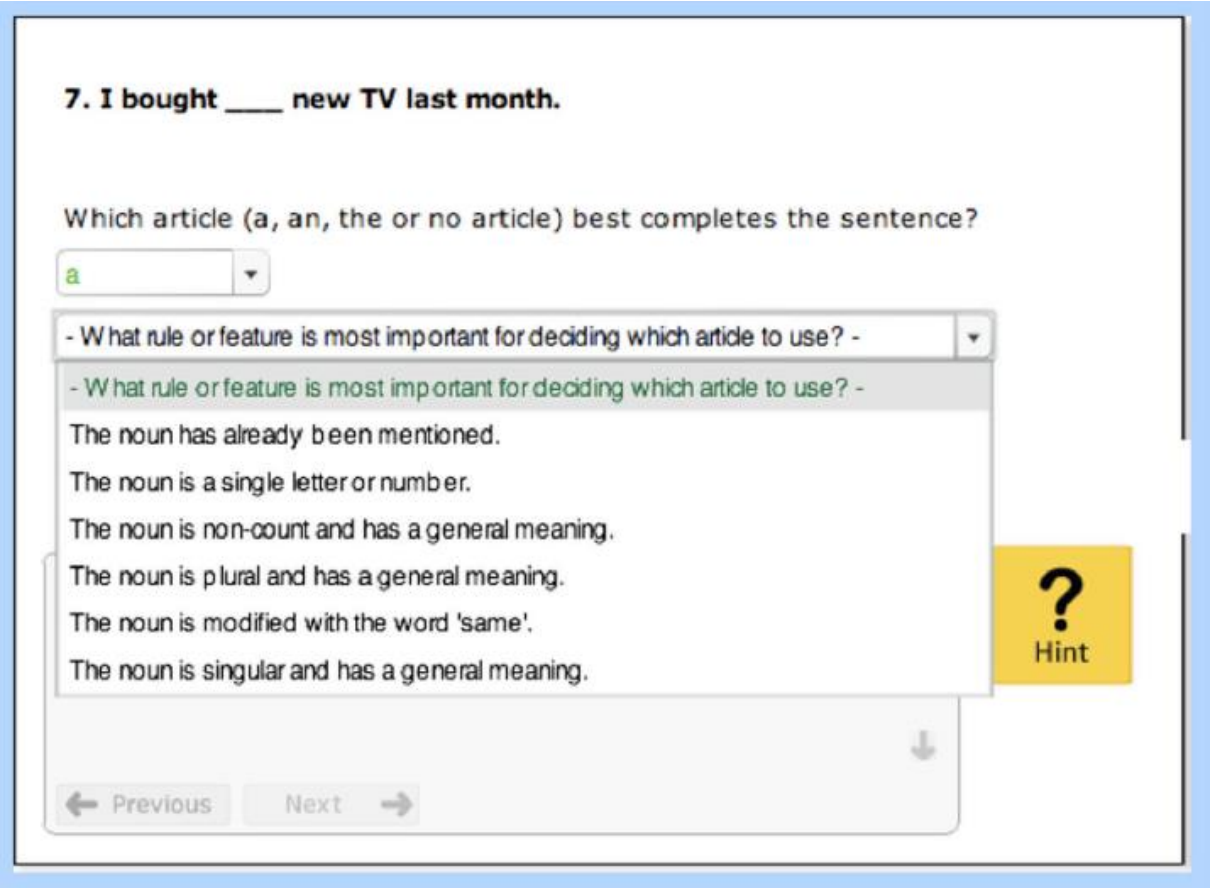
RedBlackTree Tutor



Aleven et al. (2016)

Example of Intelligent Tutoring Systems

Second Language Learning



Aleven et al. (2016)

Examples of Intelligent Tutoring Systems

Let’s Interact with some ITS avaiable at:

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

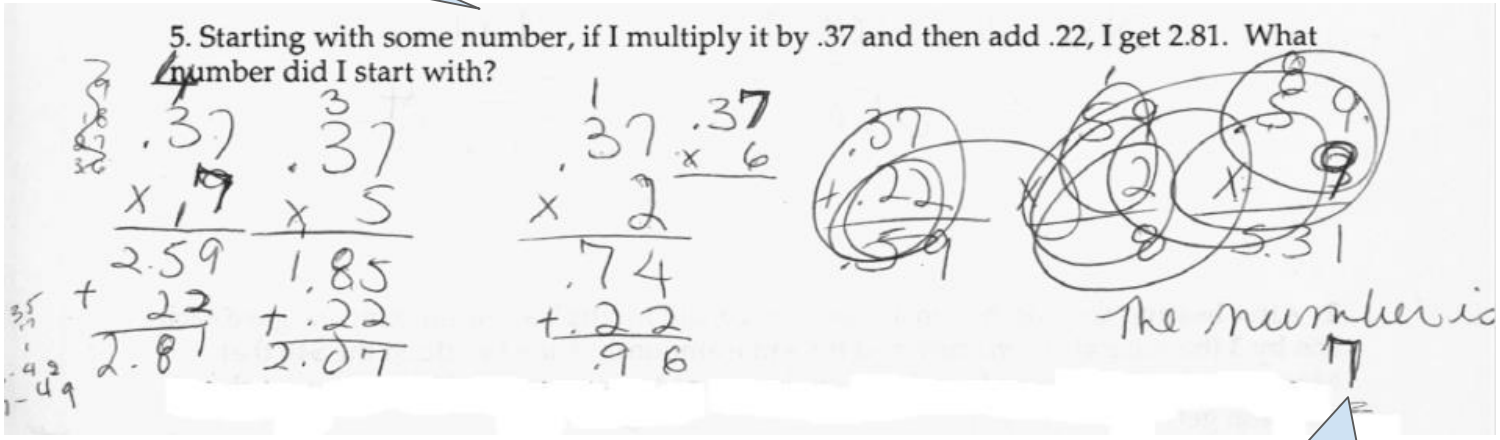
- *Working with Decimals*
- *Solving Equations -> Multi-Step Linear Equations*
- *Solving Word Problems with Pictures*
- *Area, Perimeter, Circumference*

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

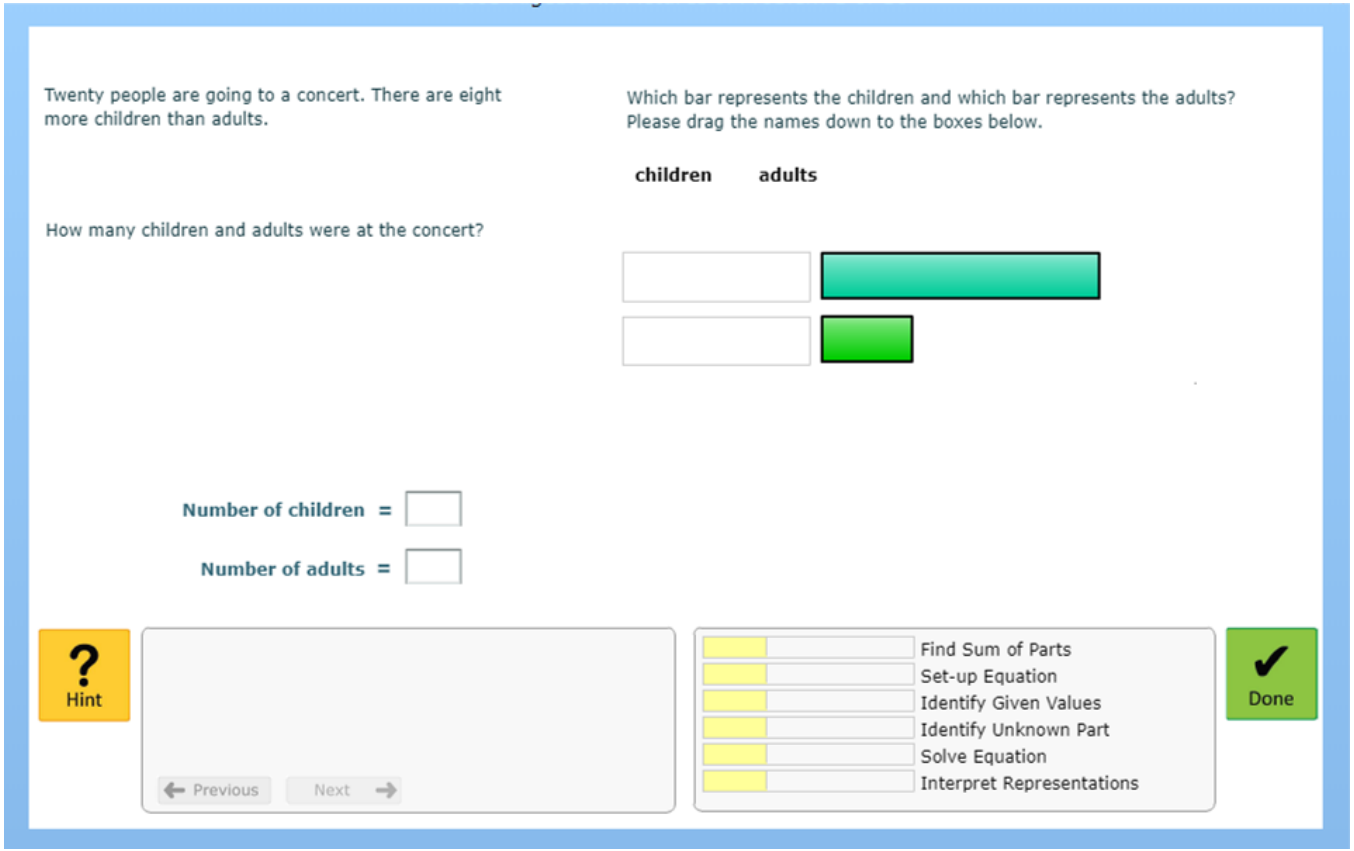
Problem statement



Koedinger & Aleven (2012)

Final Answer

Key Characteristics of ITS



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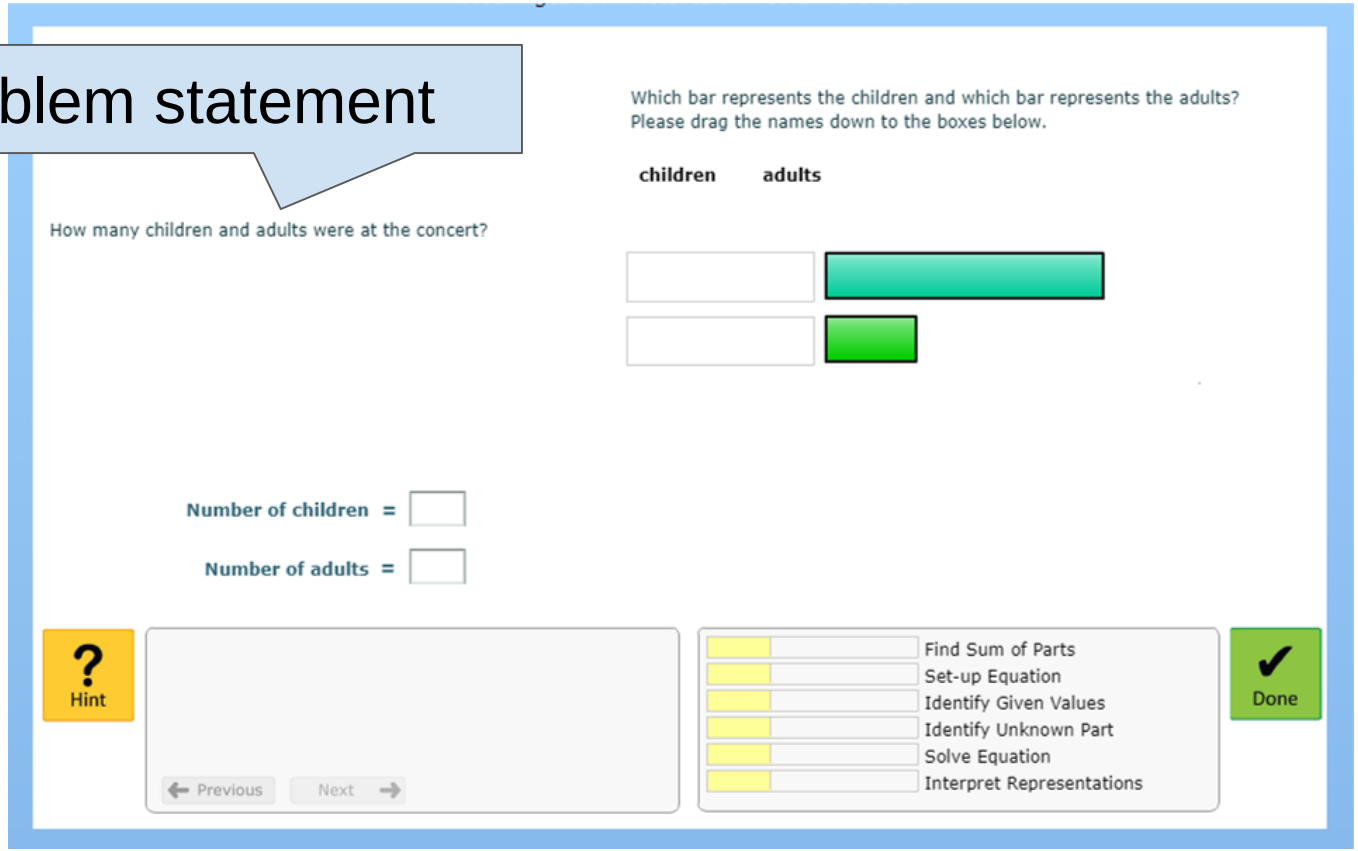

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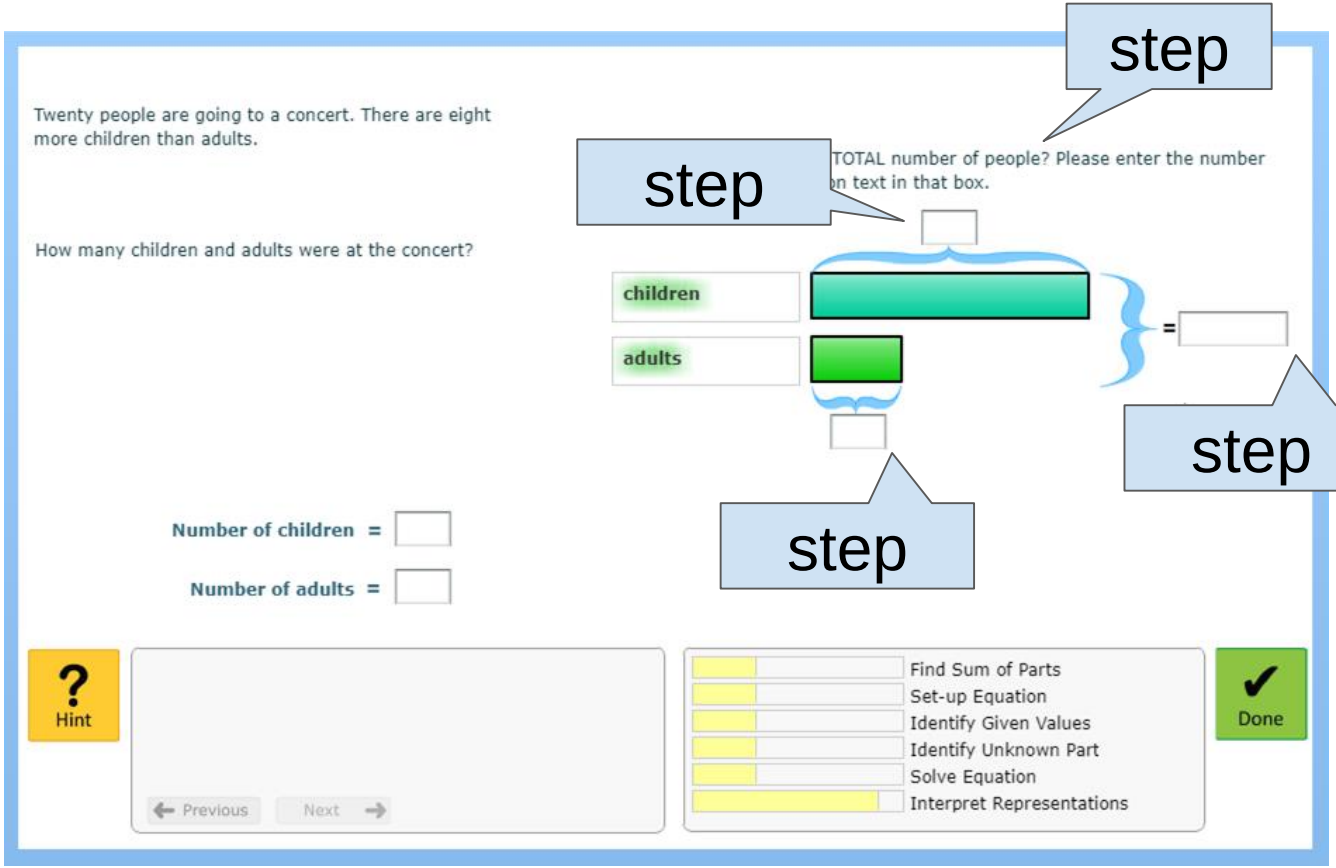

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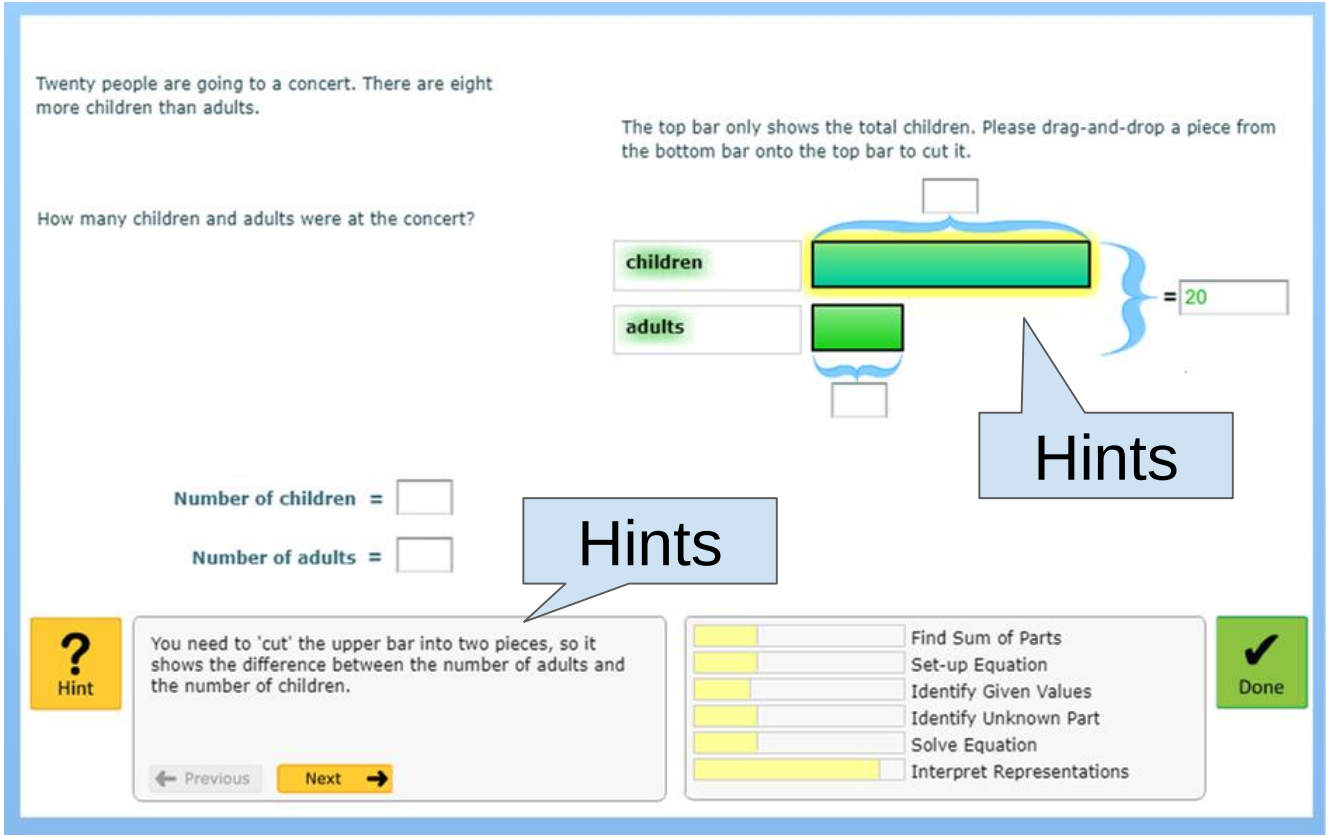

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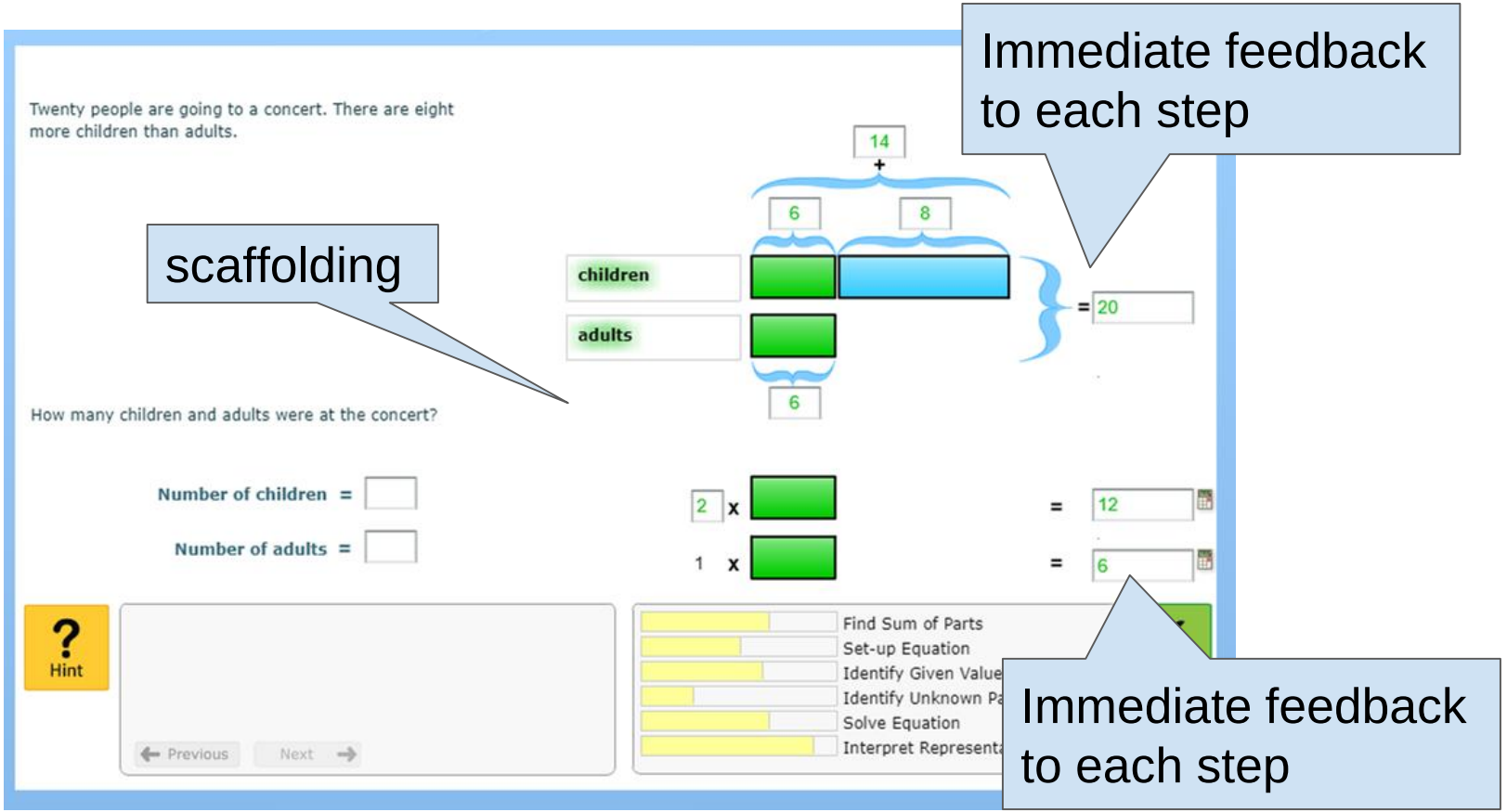

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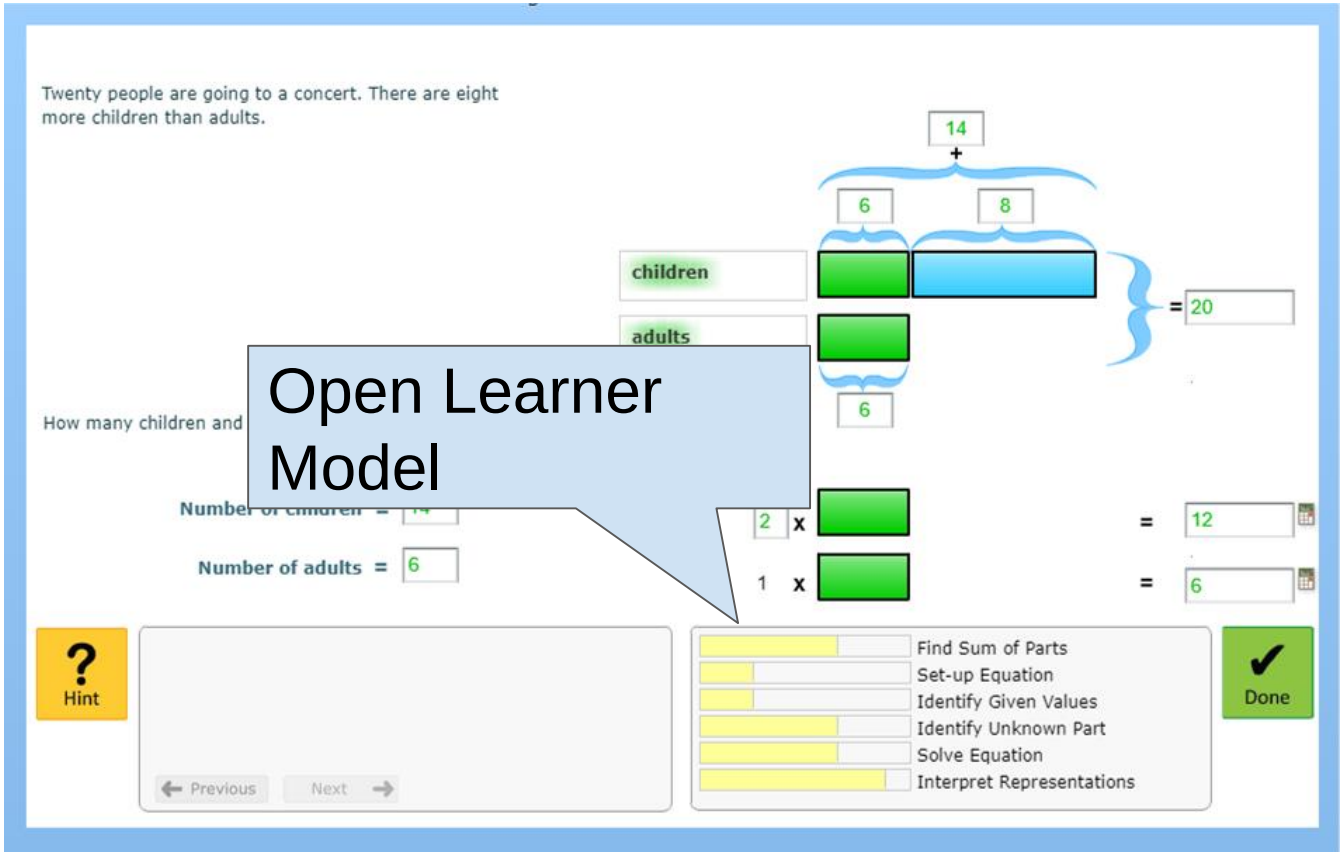

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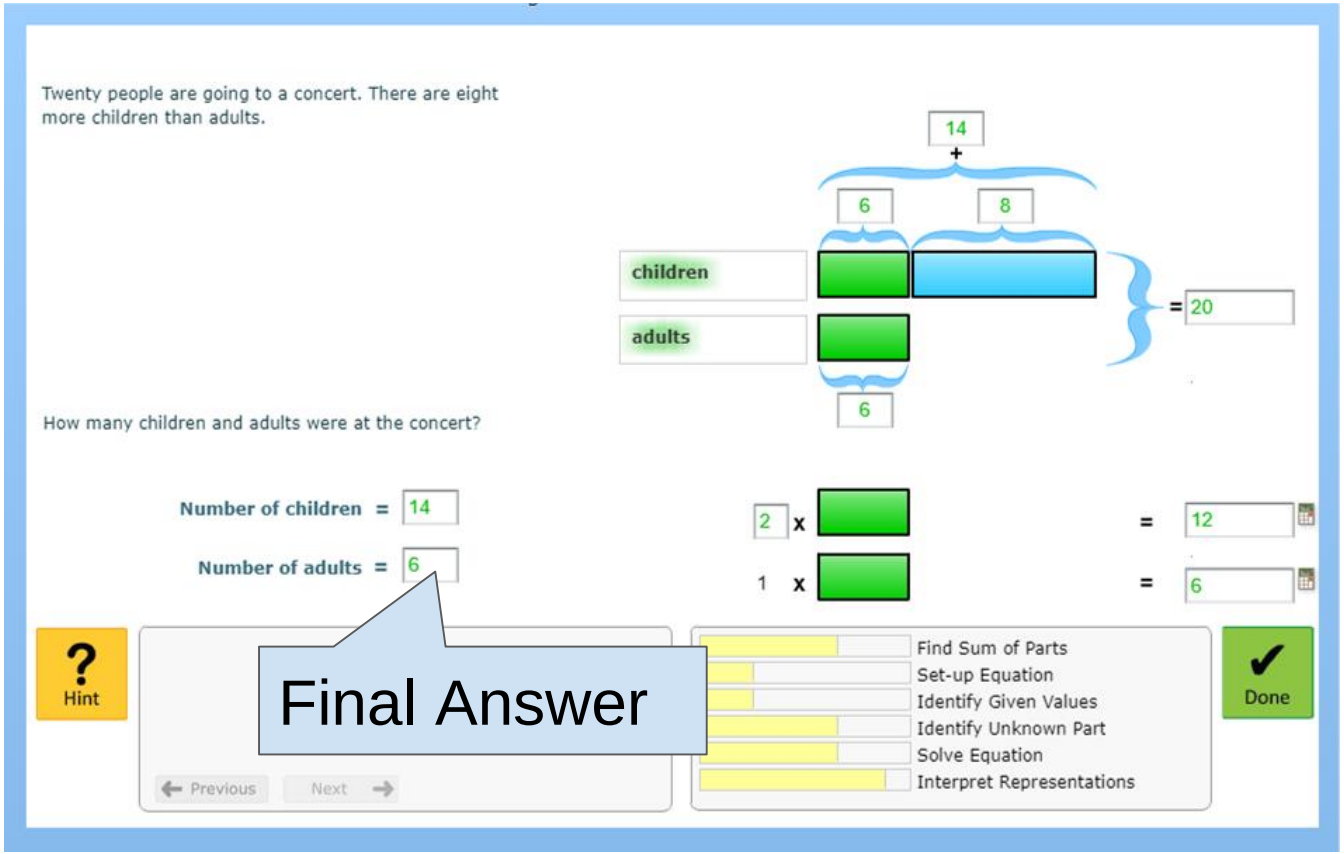


Key Characteristics of ITS

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

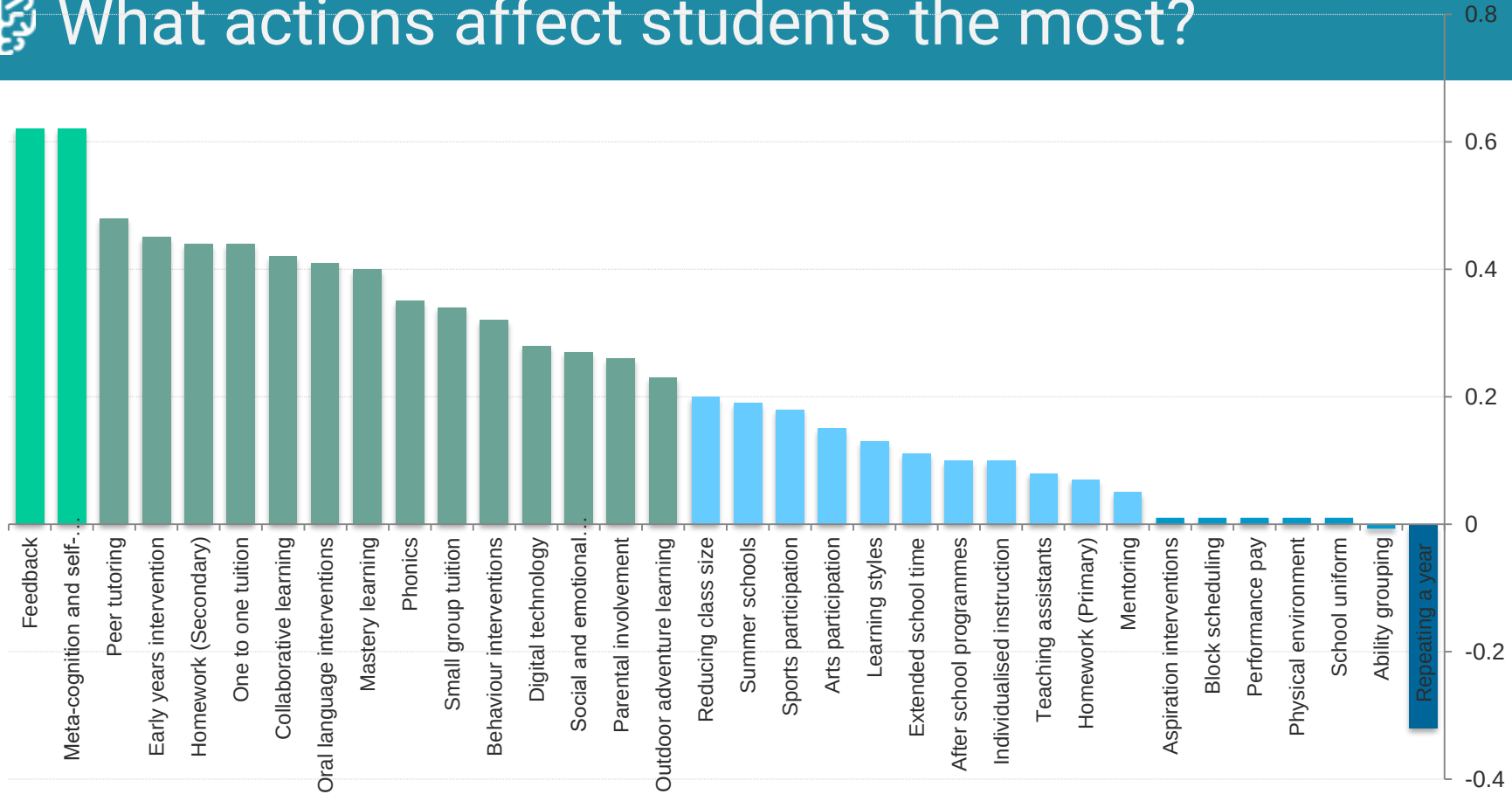
These characteristics enable an ITS to provide **feedbacks** and opportunities for students' **self-regulation**

Key Characteristics of ITS

BUT ....

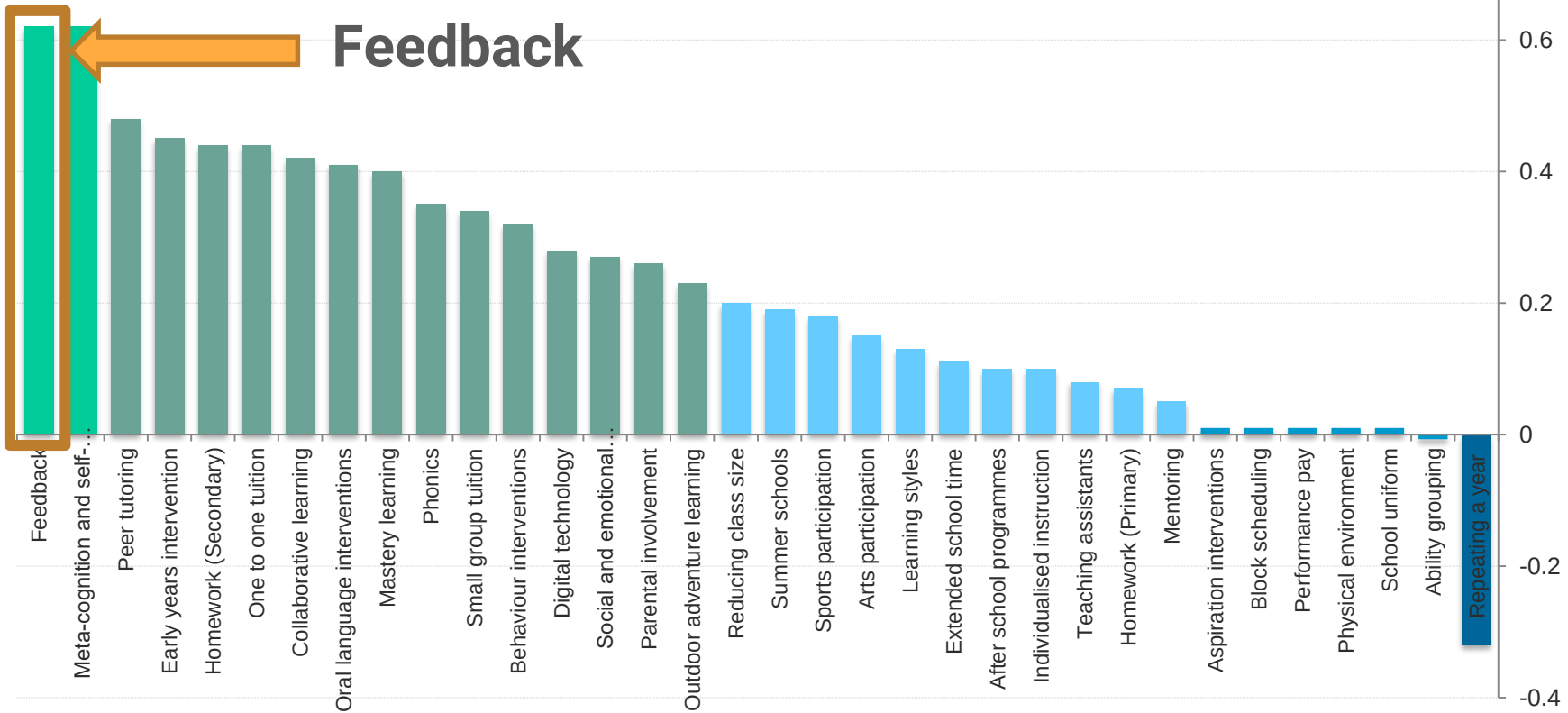
Do feedback and self-regulation help students learn better?

What actions affect students the most?



(Education Endowment Foundation, 2019)

What actions affect students the most?



(Education Endowment Foundation, 2019)

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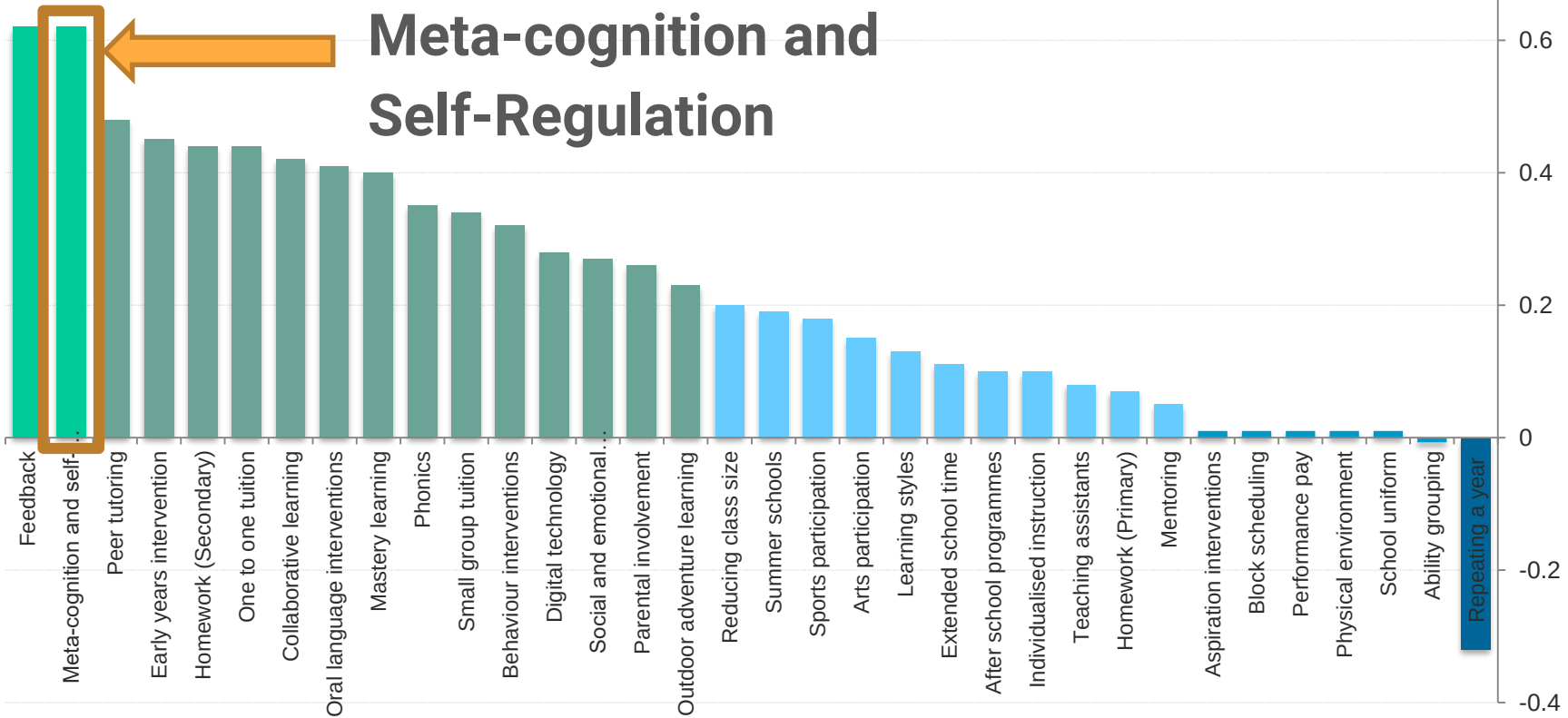


(Education Endowment Foundation, 2019)

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

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

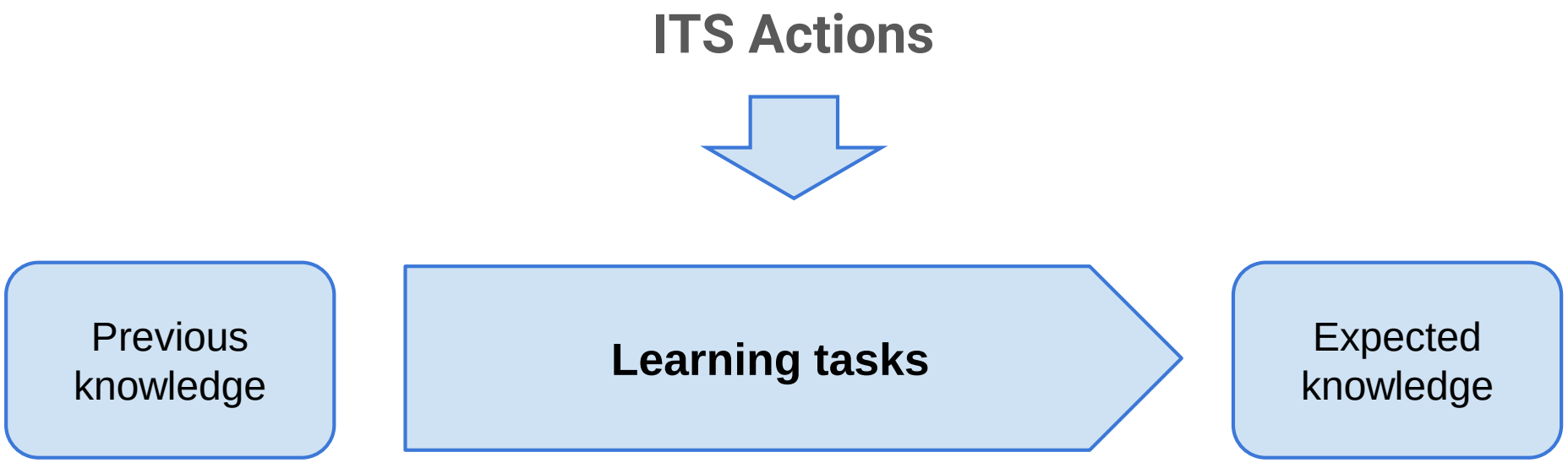
Evidência
++ : forte
+ : fraca
-- : contrária

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_etal_Handbook2017_AdaptiveLearningTechnologies.pdf

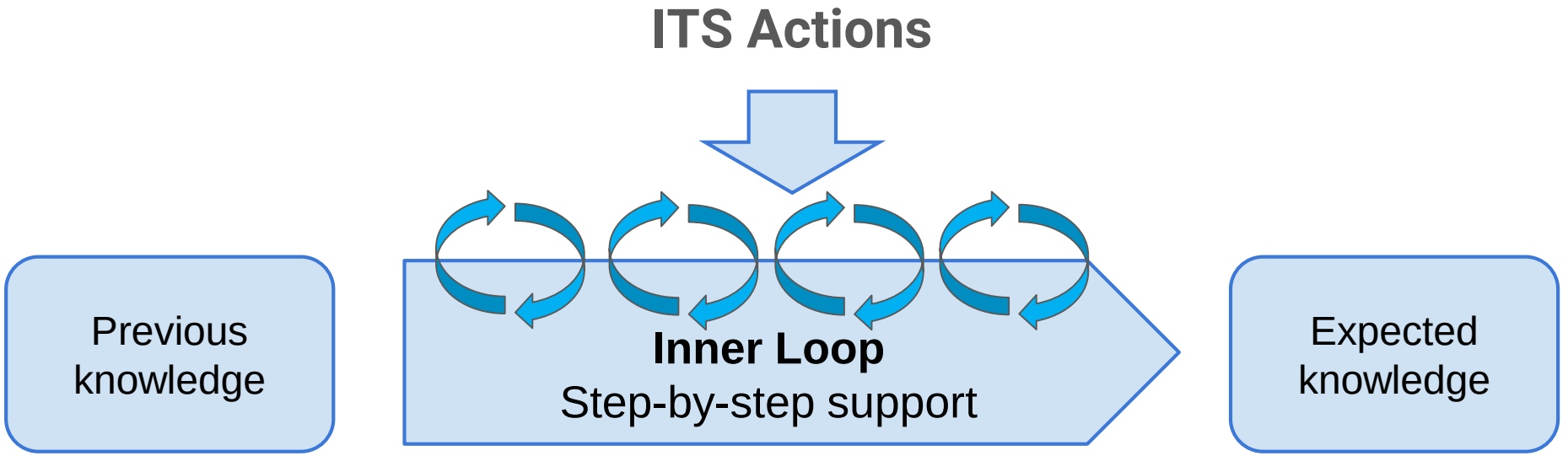
Outer Loop versus Inner Loop

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

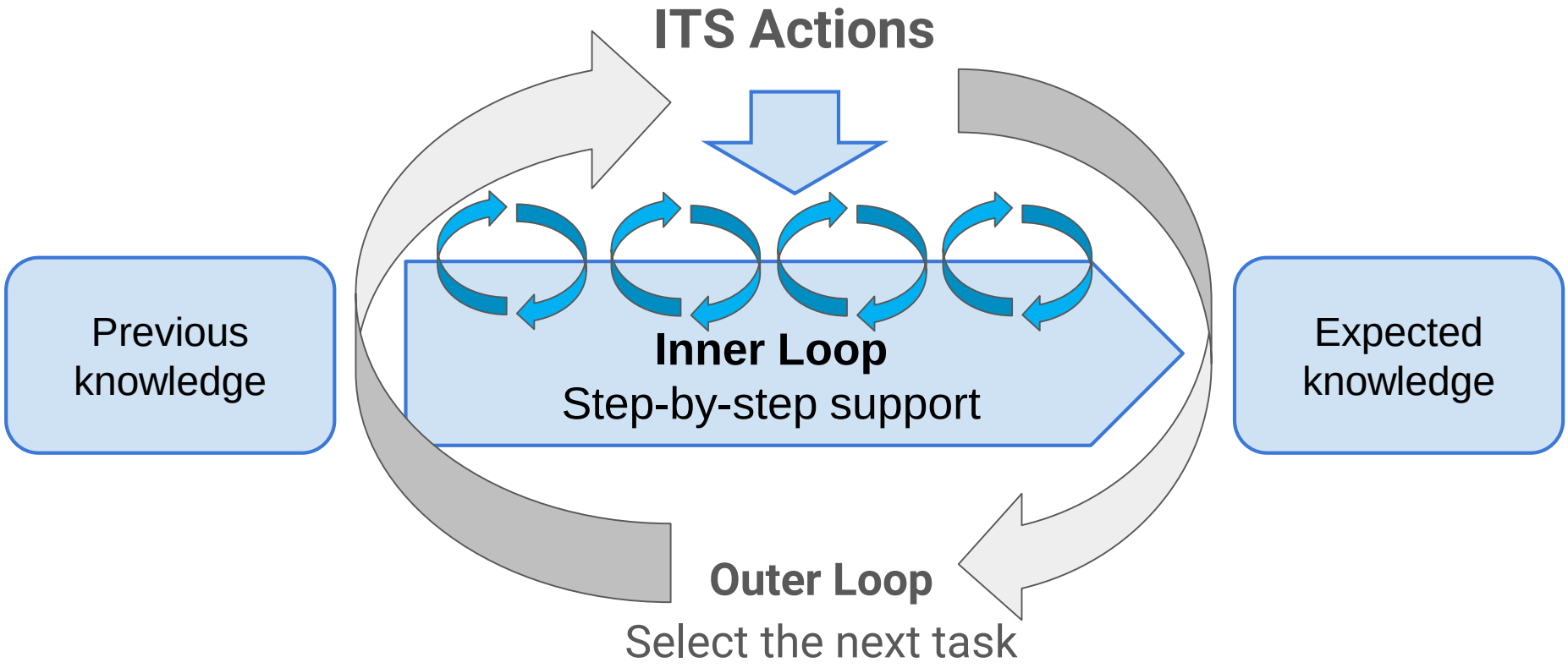
Outer Loop vs. Inner Loop



Outer Loop vs. Inner Loop



Outer Loop vs. Inner Loop



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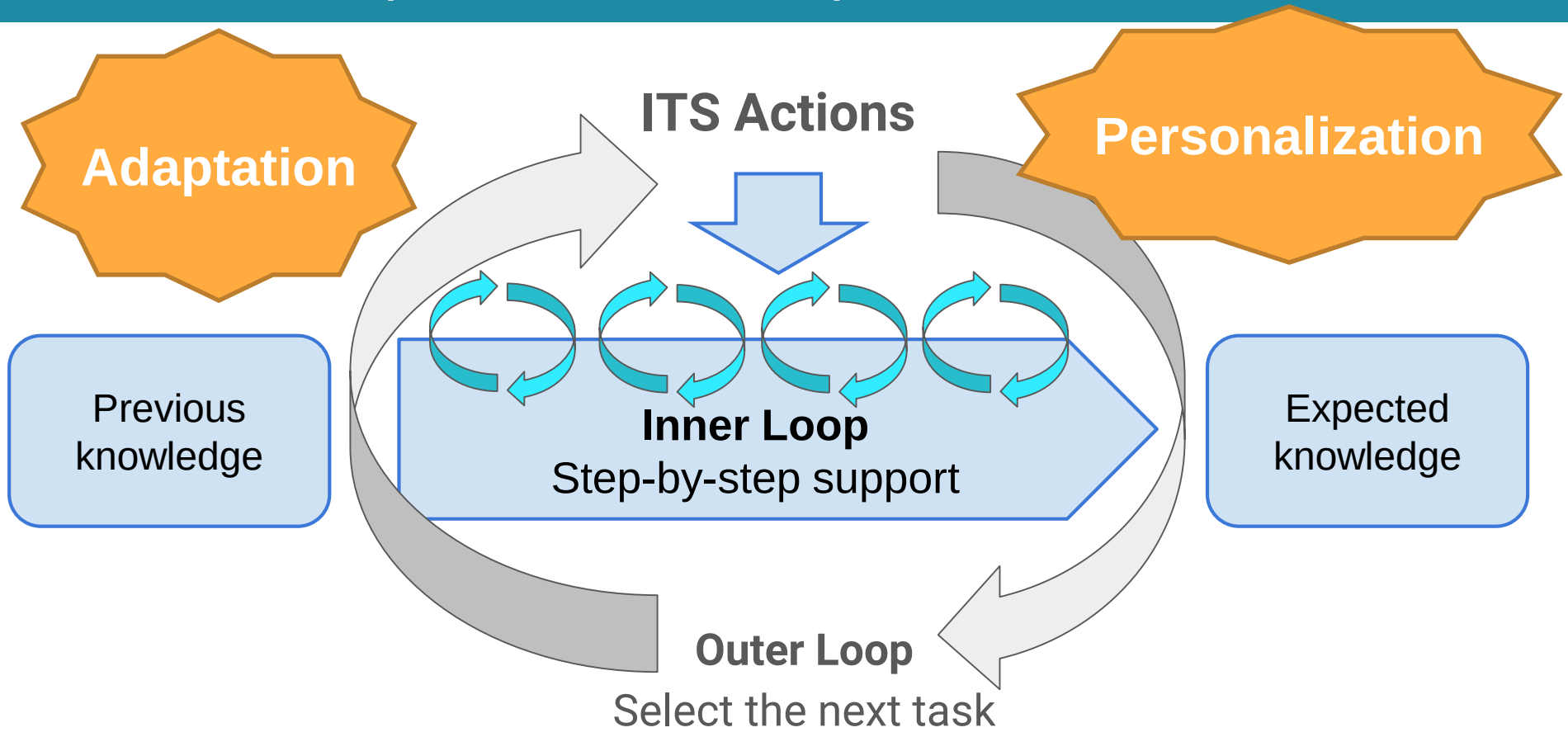

Características essenciais - STI

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

Inner Loop

There are several approaches to adequately operationalize the inner loop so it can provide step-by-step guidance to students. We will presente 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)

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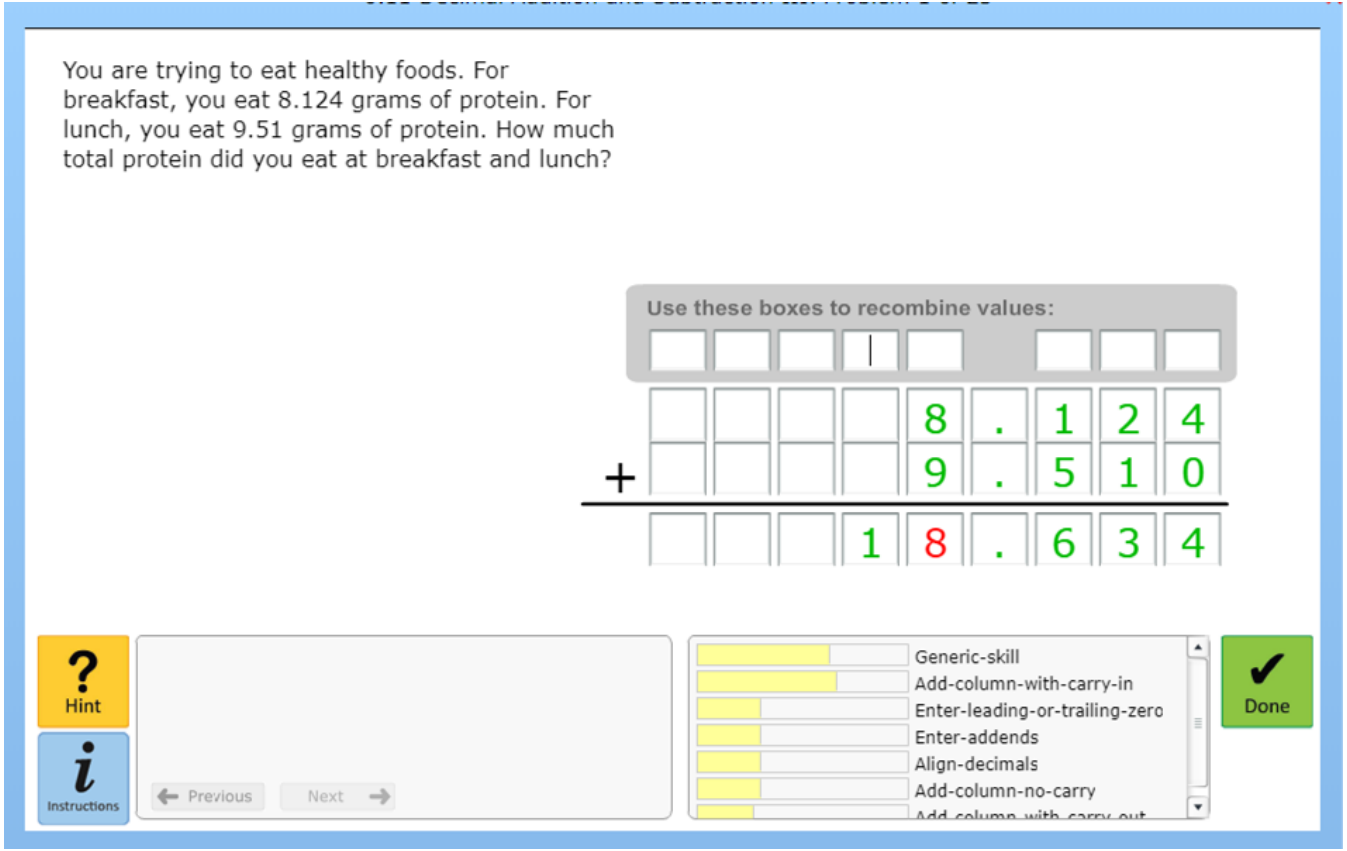
Inner Loop – Minimum Feedback

Example:

Feedback provided immediately after an action

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



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2. **Specific feedback to each step**
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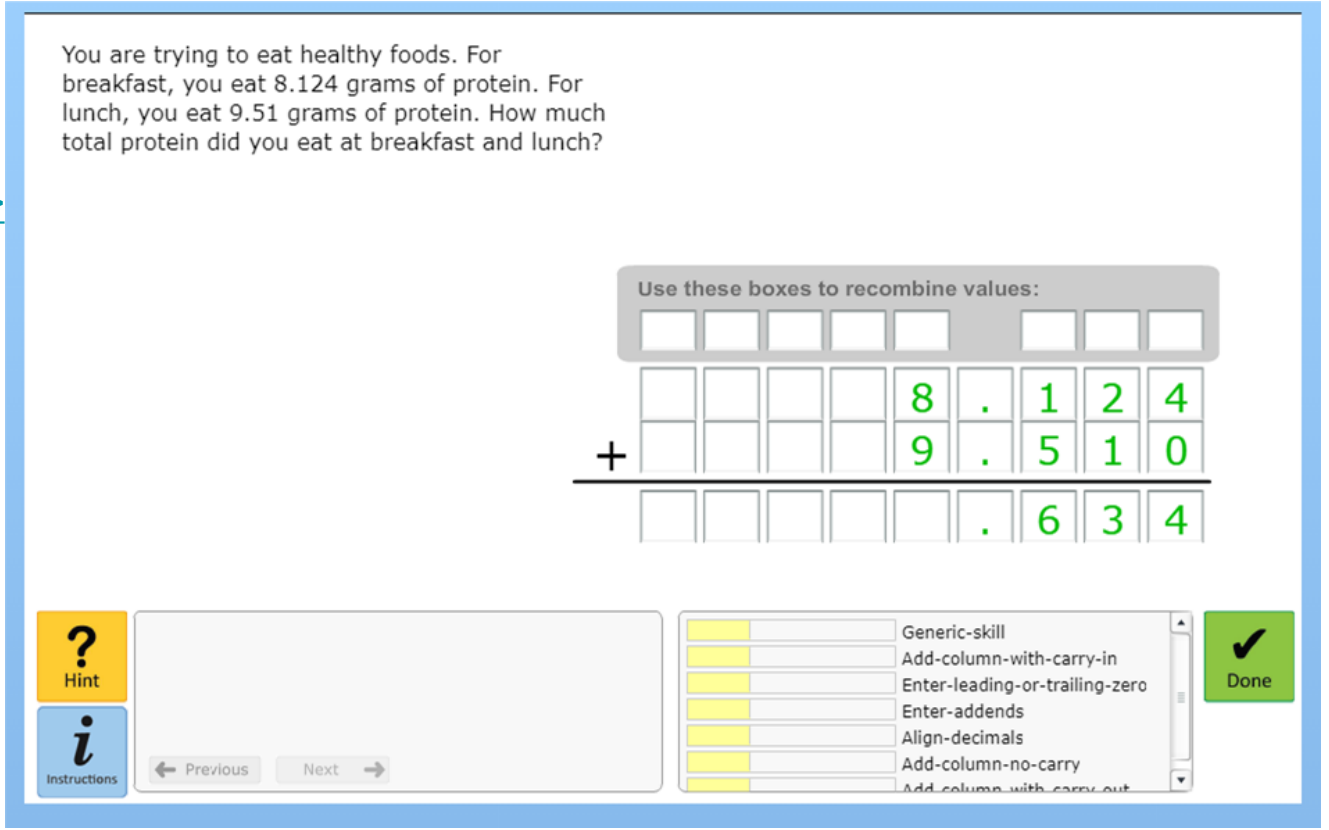
Inner Loop – Specific Feedback

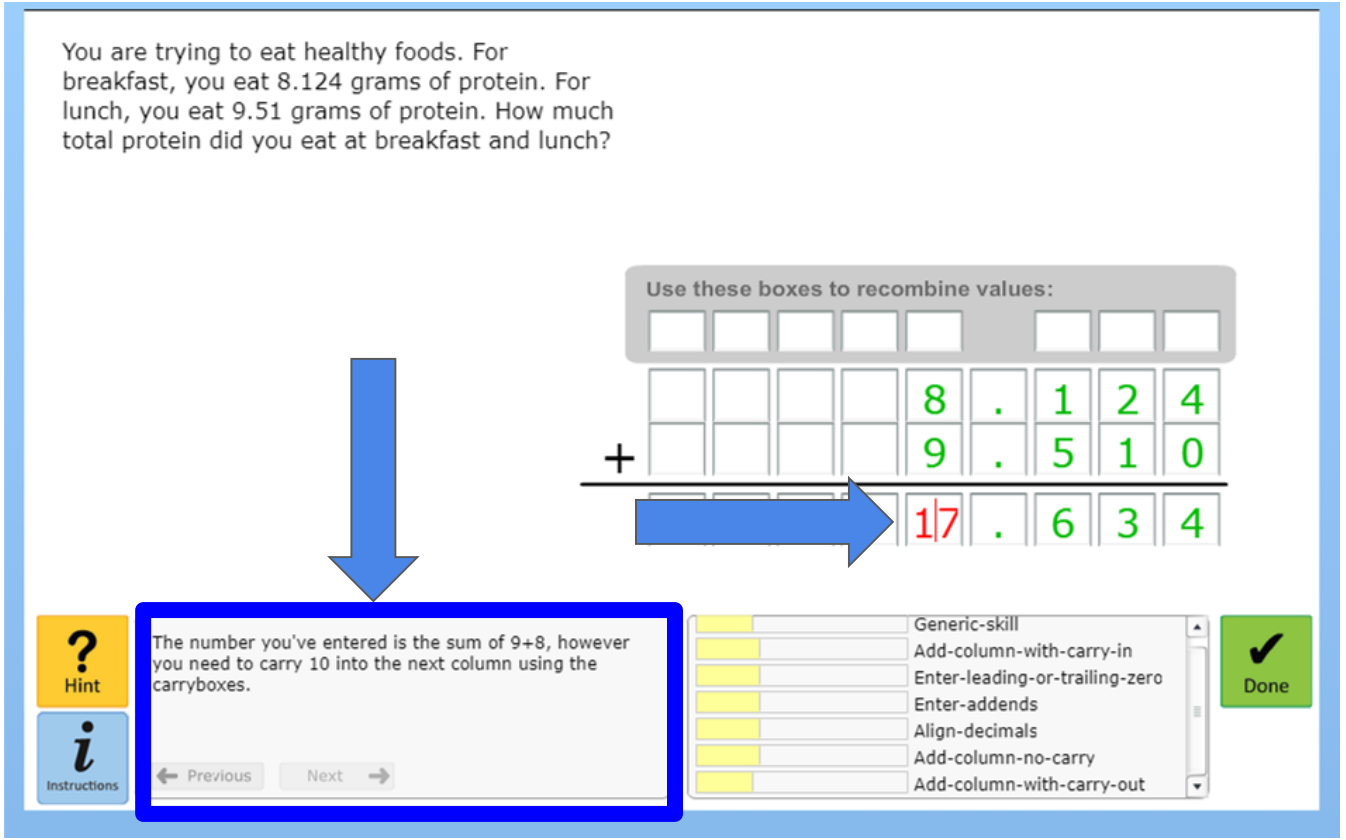
Exemple:

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



Inner Loop – Specific Feedback

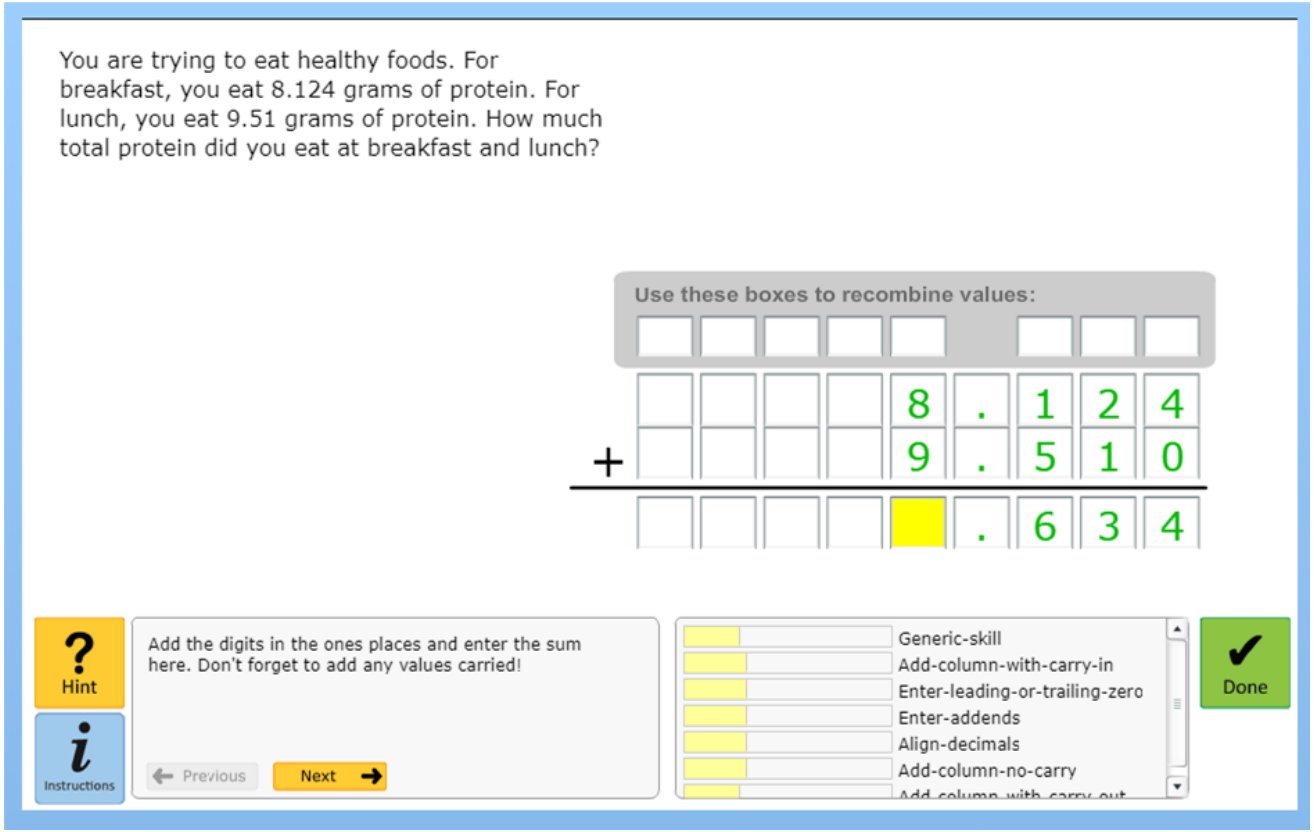
1. Specific hint to a common error.



Inner Loop – Specific Feedback

2. On demand specific hints to complete a step:

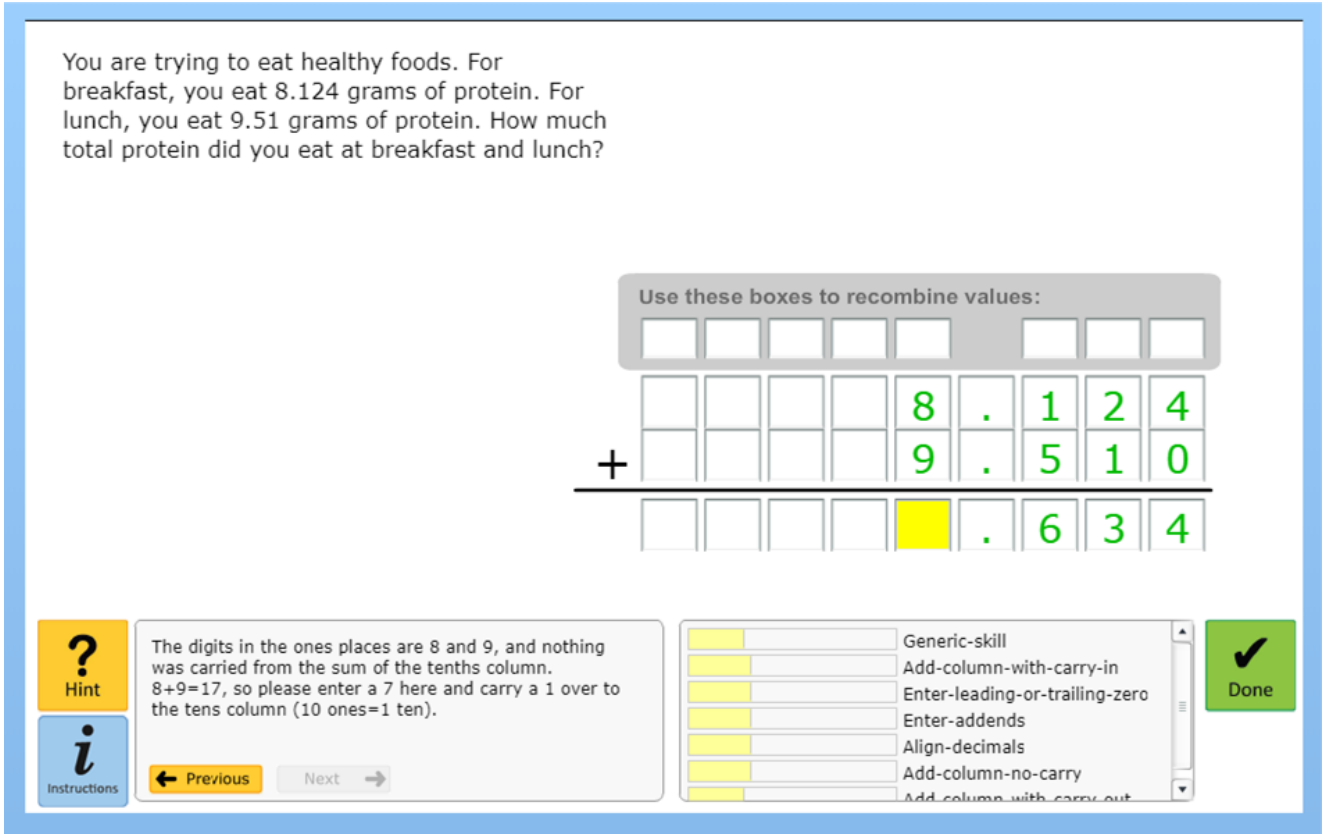
Hints can be procedural or conceptual. In this example, we have a procedural hint.



Inner Loop – Specific Feedback

On demand specific hints to complete a step:

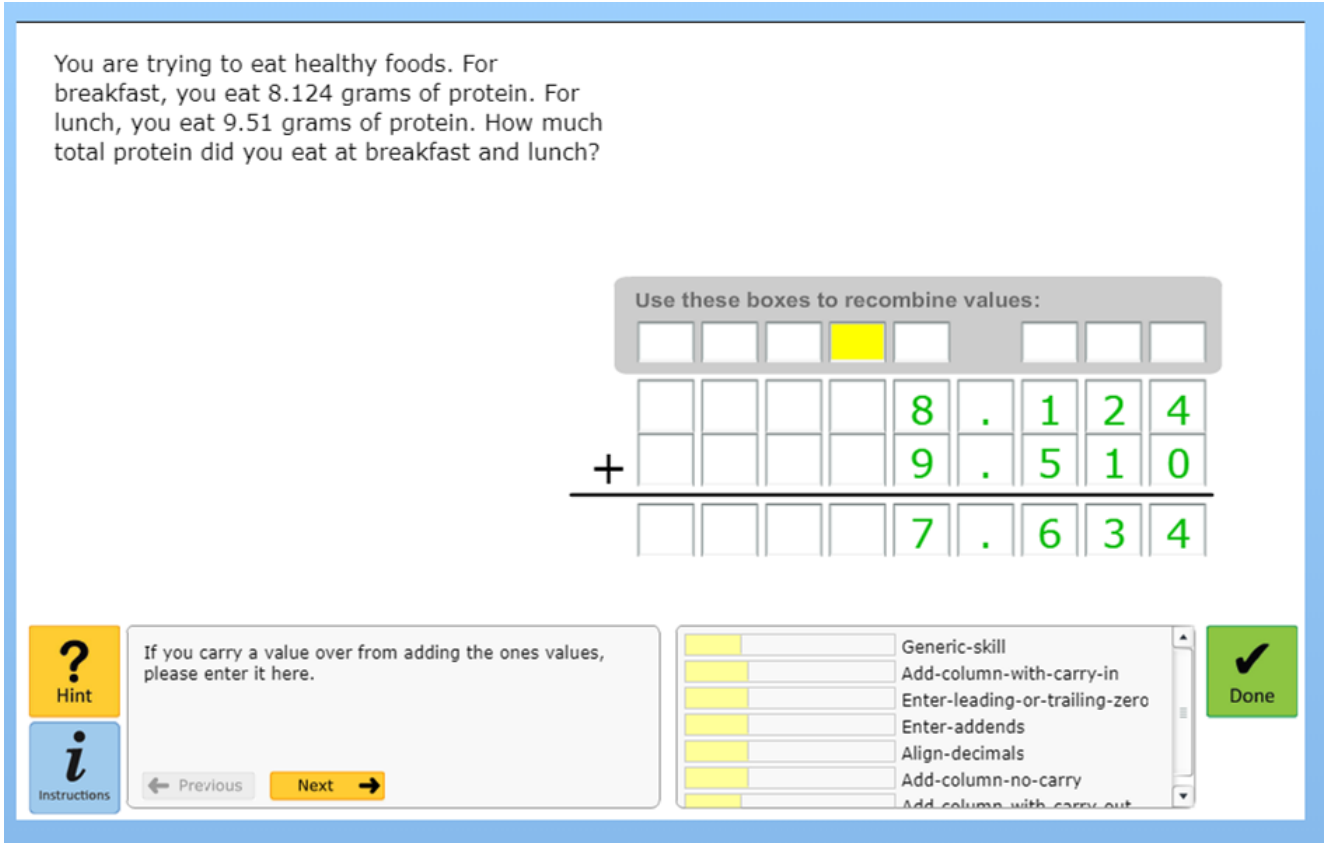
If students require more assistant, the hints become more specific.



Inner Loop – Specific Feedback

On demand specific hints to complete a step:

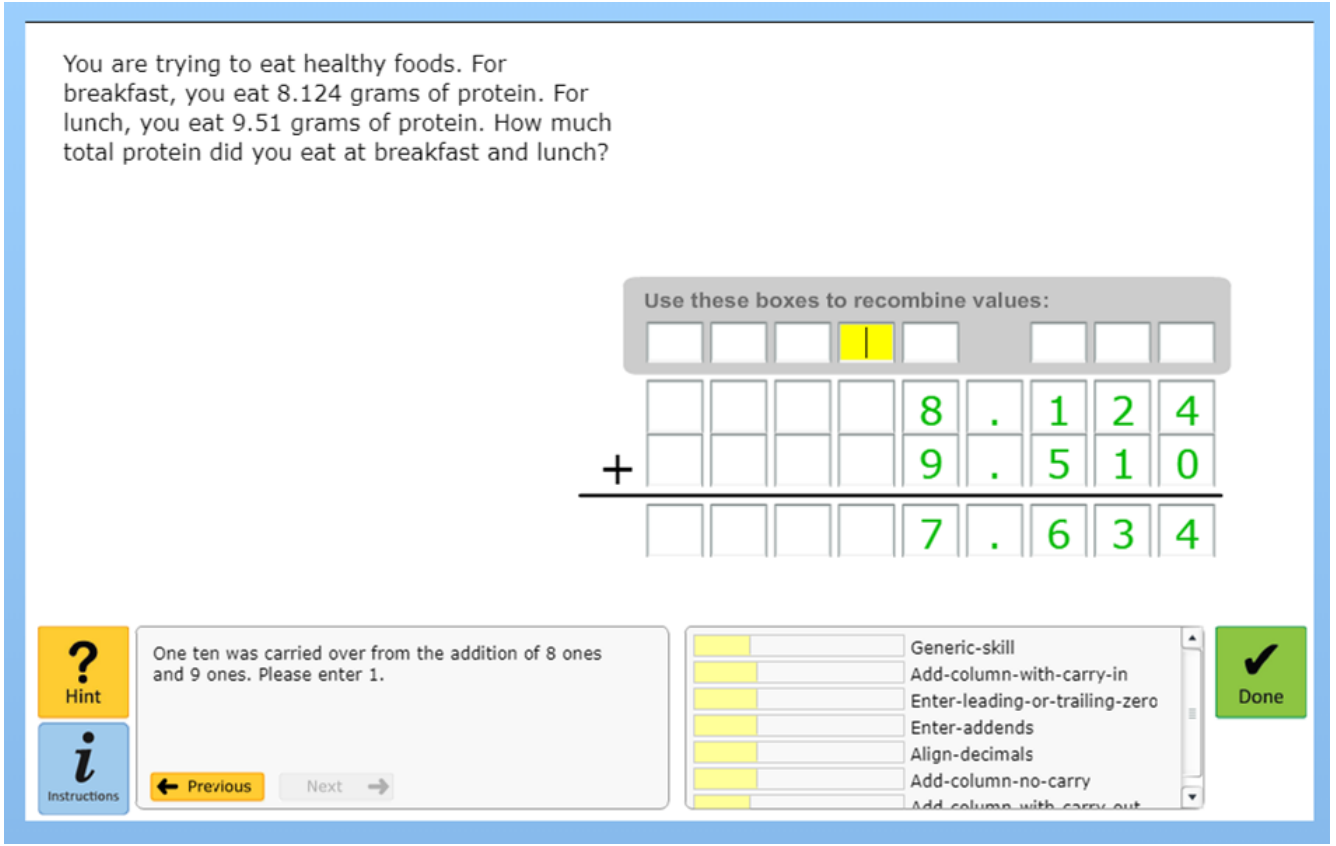
Hints usually request students to think about what should be done to complete the step.



Inner Loop – Specific Feedback

On demand specific hints to complete a step:

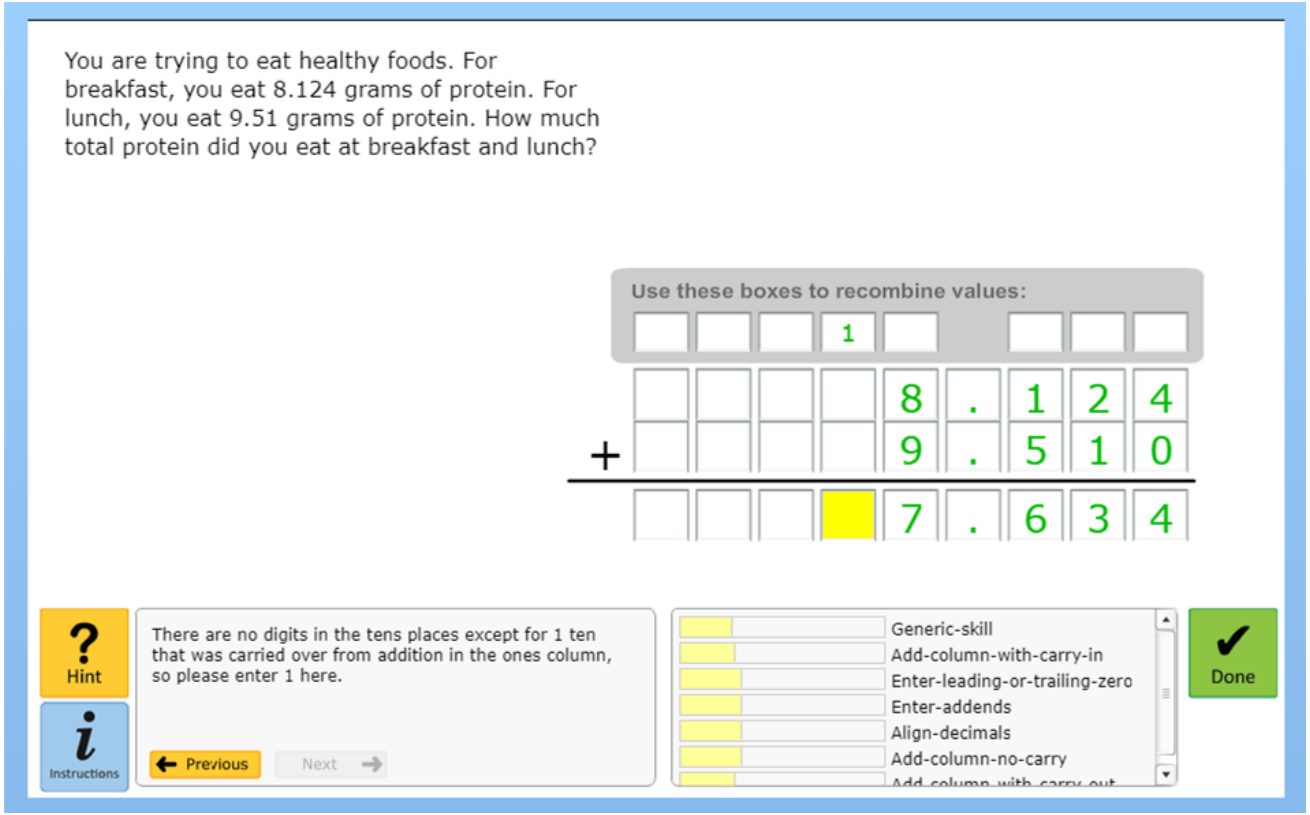
Hints also consider the previous completed steps.



Inner Loop – Specific Feedback

On demand specific hints to complete a step:

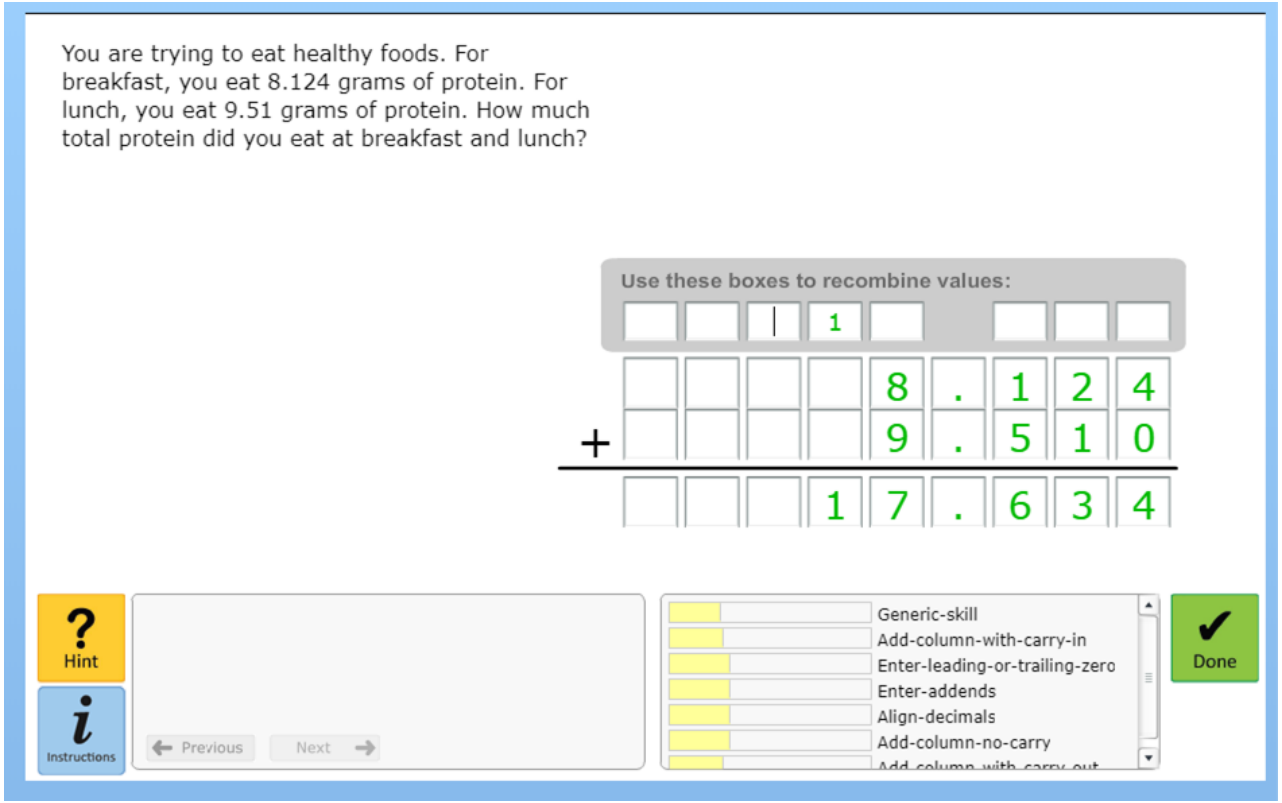
Hints become more specific after each request until reaching a point where the ITS presents exactly what should be the input.



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*[1])



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

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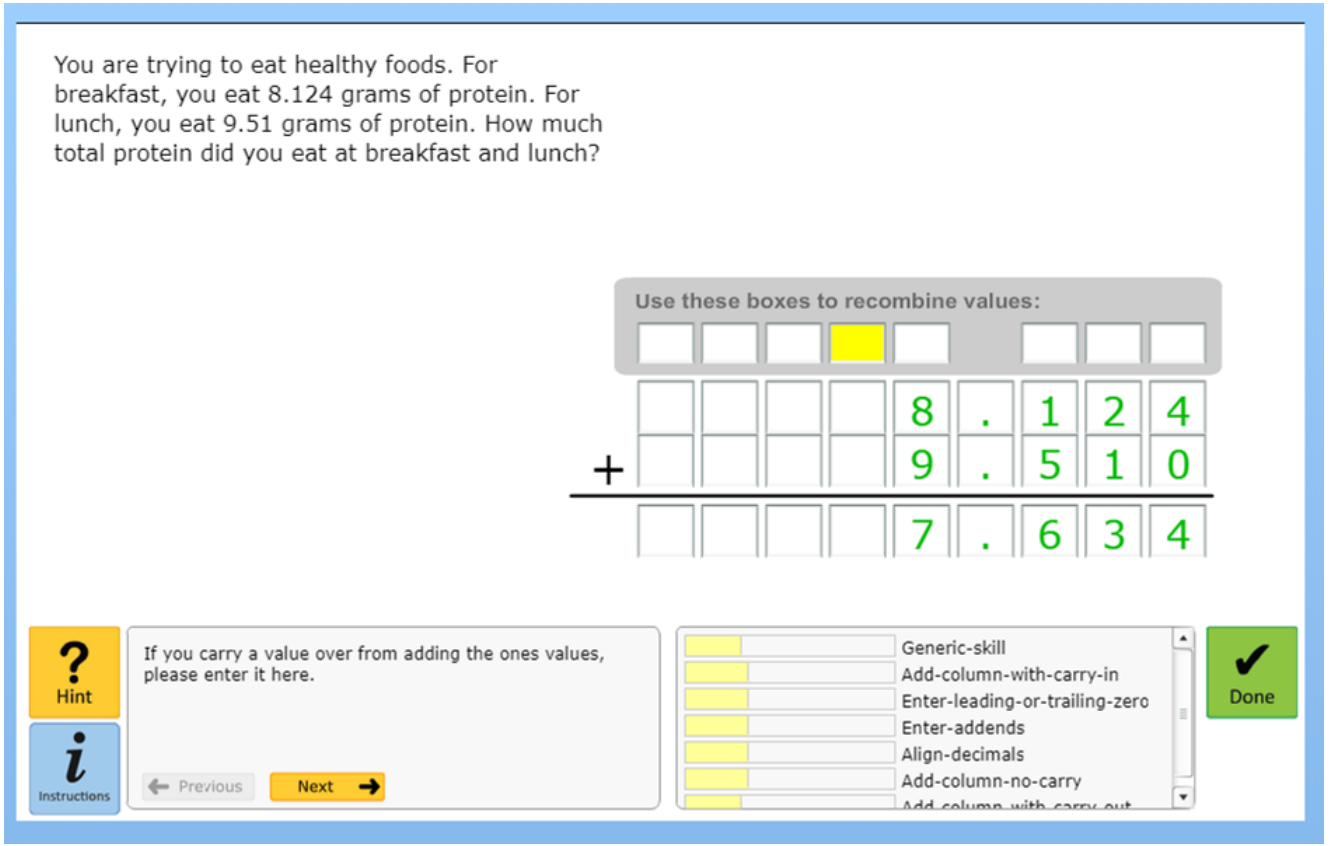
2. Specific feedback to each step
3. **Hints to perform the next step**
4. Assessment of student's knowledge
5. Review of students' solution (worked example)

Inner Loop

Example:

Highlight the best next step to be executed.



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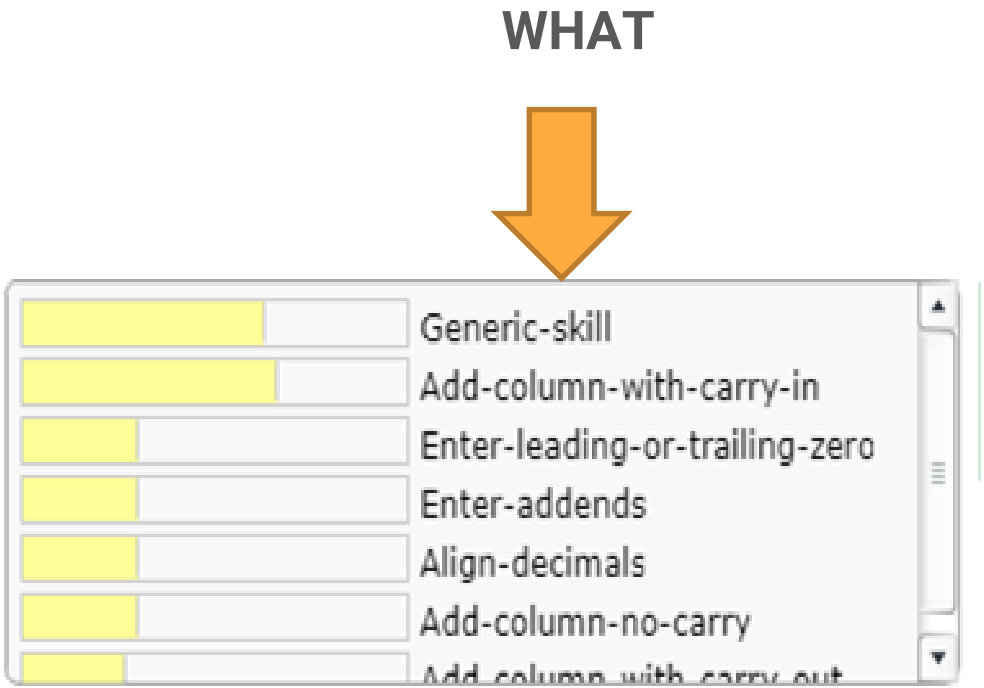
4. **Assessment of student's knowledge**
5. Review of students' solution (worked example)

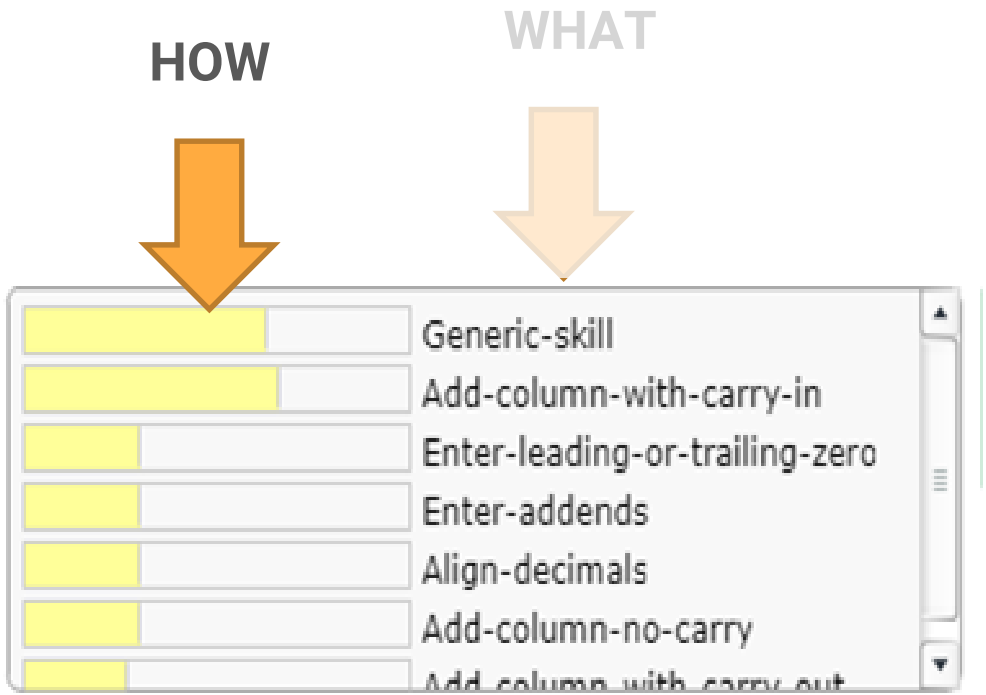
Inner Loop - Assessment of student's knowledge

- **WHAT** to assess?



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

Inner Loop

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

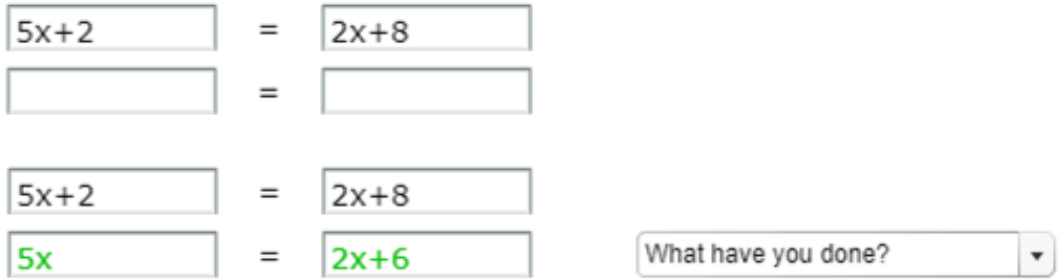
5x+2	=	2x+8
	=	

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



Inner Loop - Review of students' solution

Example:

Ask students to think about each problem step

5x+2	=	2x+8		
	=			
5x+2	=	2x+8		
5x	=	2x+6	What have you done?	
5x+2	=	2x+8		
5x	=	2x+6	subtract [?] from both sides	

Inner Loop - Review of students' solution

Example:

Ask students to think about each problem step

5x+2	=	2x+8		
	=			
5x+2	=	2x+8		
5x	=	2x+6	What have you done?	
5x+2	=	2x+8		
5x	=	2x+6	subtract [?] from both sides	
5x+2	=	2x+8		
5x	=	2x+6	subtract [?] from both sides	2
	=			

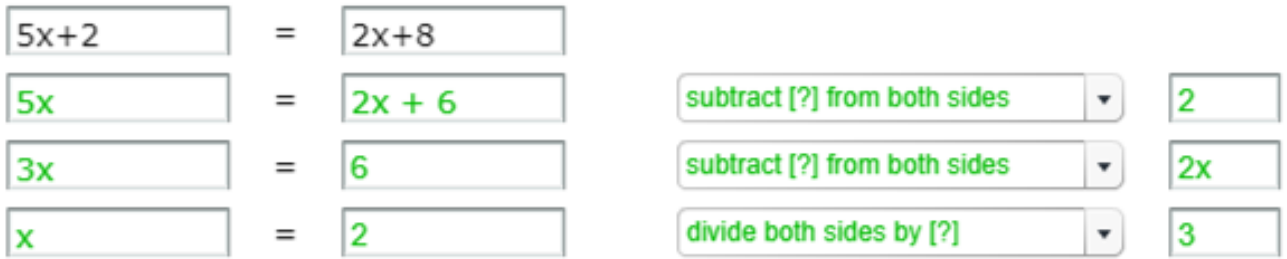
Inner Loop - Review of students' solution

Example:

1. Show the list of steps

2. Show the minimum feedback

3. Give opportunities to think about each step



Inner Loop - Review of students' solution

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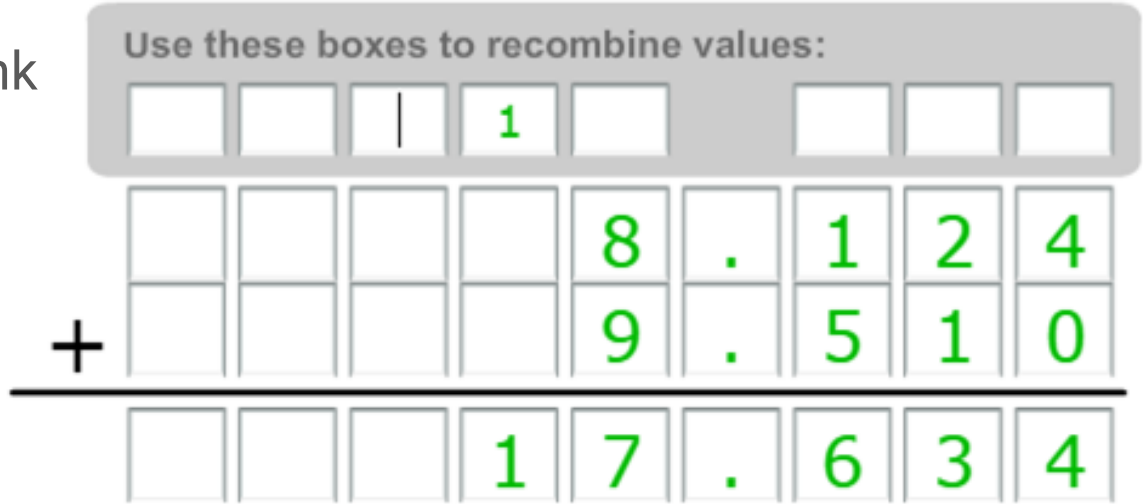


Inner Loop

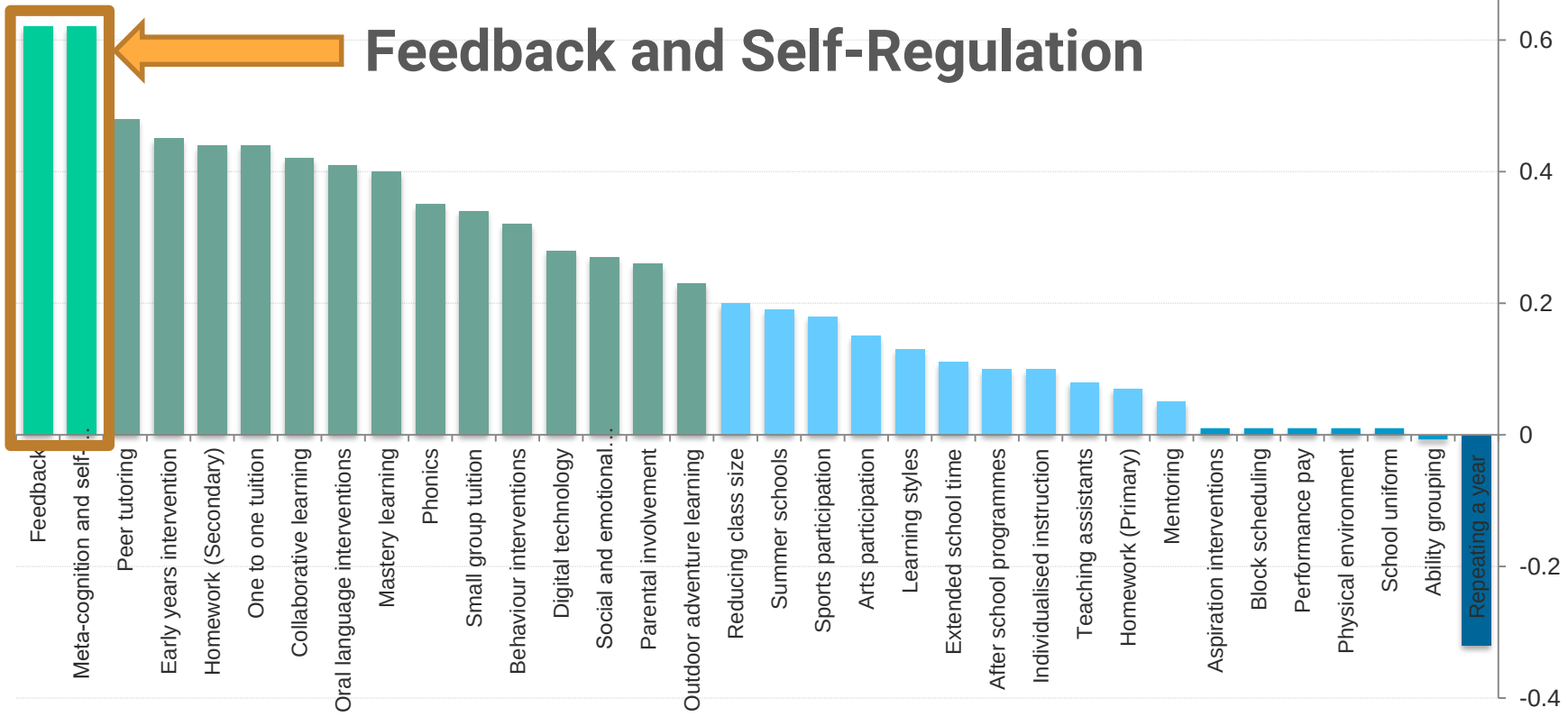
In Summary,

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



(Education Endowment Foundation, 2019)

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.

(Aleven et al., 2006; 2009)

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

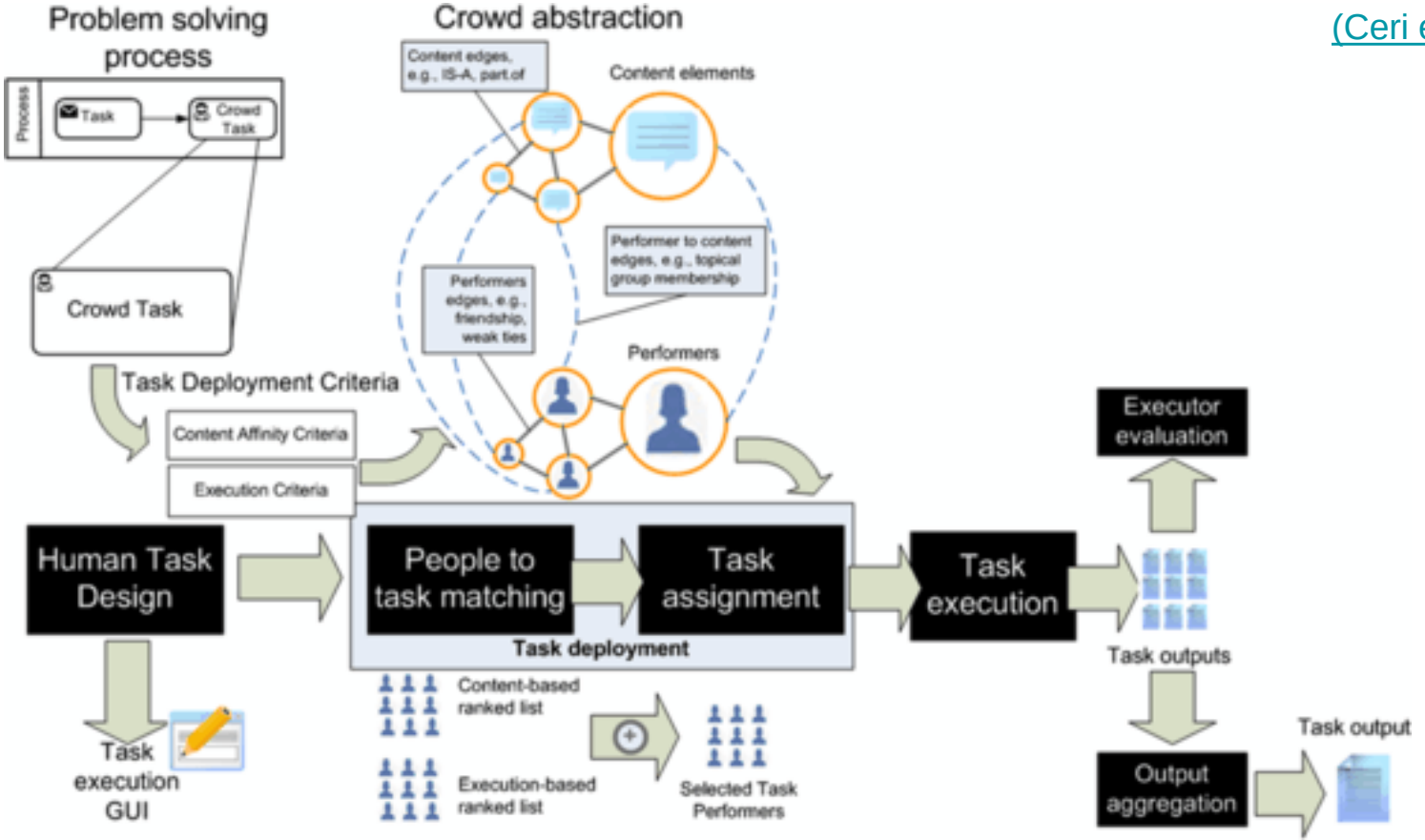
1. How to develop an approach to “**automatize**” and speed up the implementation of the inner loop to any content and domain?
    - Human-computation
2. How to personalize the inner loop to better engage students during the learning process?
    - Gamification
    - Persuasion
    - Multimedia learning

Ongoing Research

Challenges

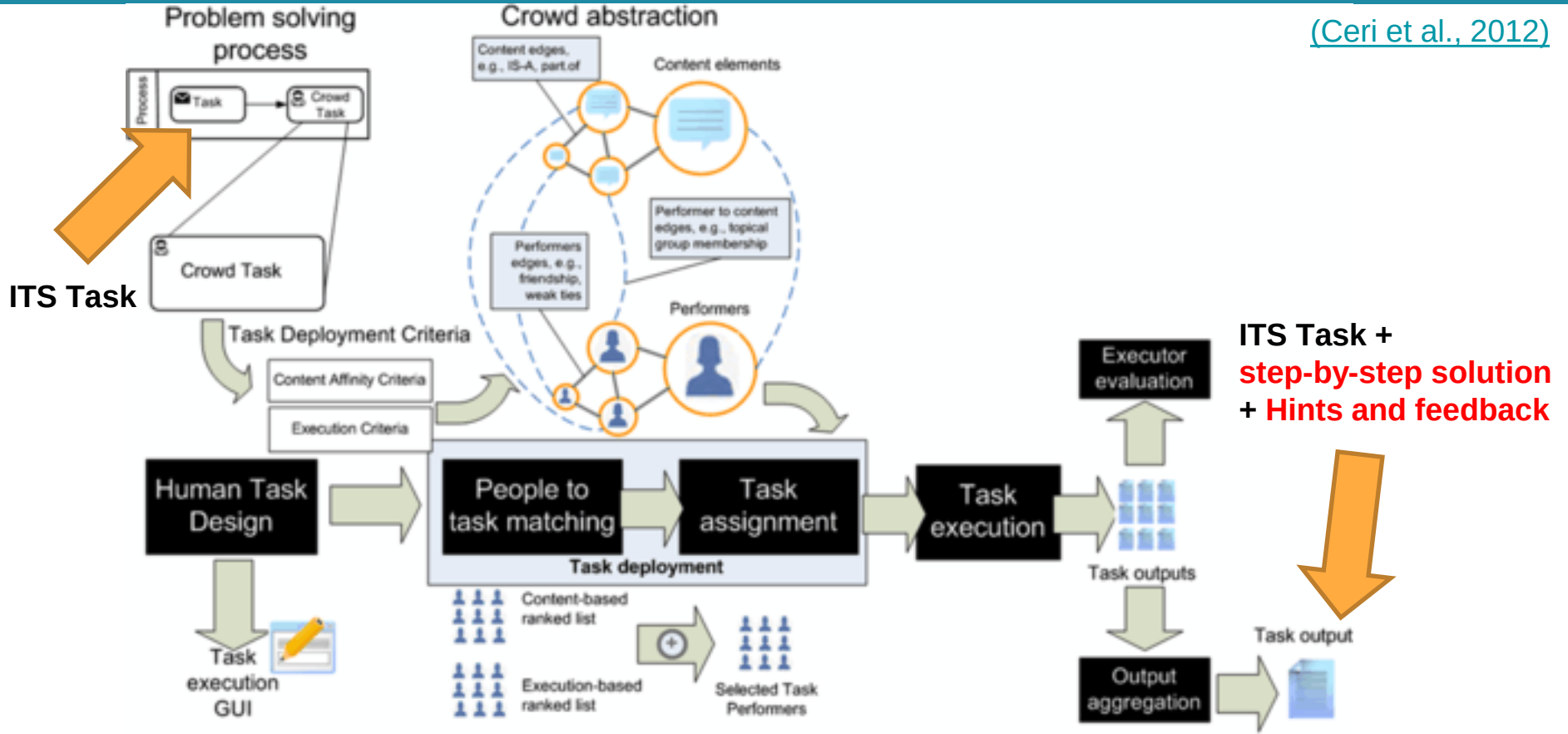
1. How to develop an approach to “**automatize**” and speed up the implementation of the inner loop to any content and domain?
    - Human-computation
2. How to personalize the inner loop to better engage students during the learning process?
    - Gamification
    - Multimedia learning

Creating the inner loop with human computation



(Ceri et al., 2012)

Creating the inner loop with human computation



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Challenges

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    - Gamification
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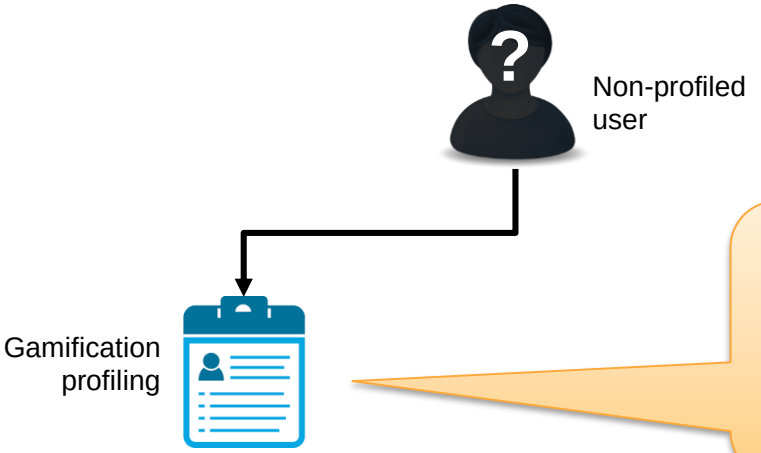
Approach to personalized inner loop design



- Best practices & theories [1,2,3]
- Gamiflow Framework
- QPJ-BR[4] Framework to classify player roles [5]

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.
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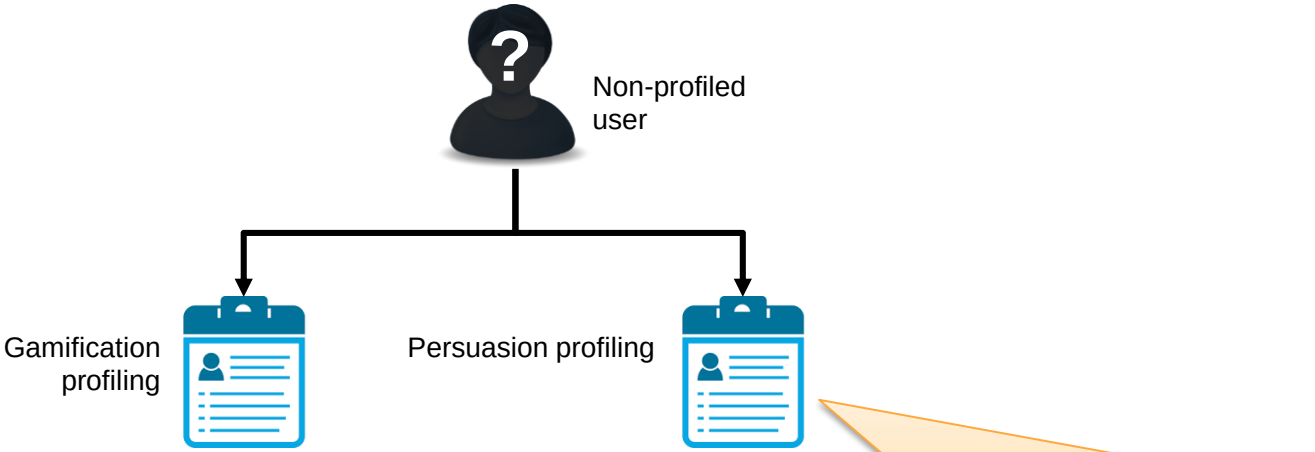
4 ANDRADE, F. R. H.; MARQUES, L. B.; BITTENCOURT, I. I.; ISOTANI, S. QPJ - BR : Questionário para Identificação de Perfis de Jogadores para o Português - Brasileiro. CBIE, p. 637–646, 2016.
5 BORGES, S. S. et al. A Link Between Worlds: Towards a Conceptual Framework for Bridging Player and Learner Roles 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

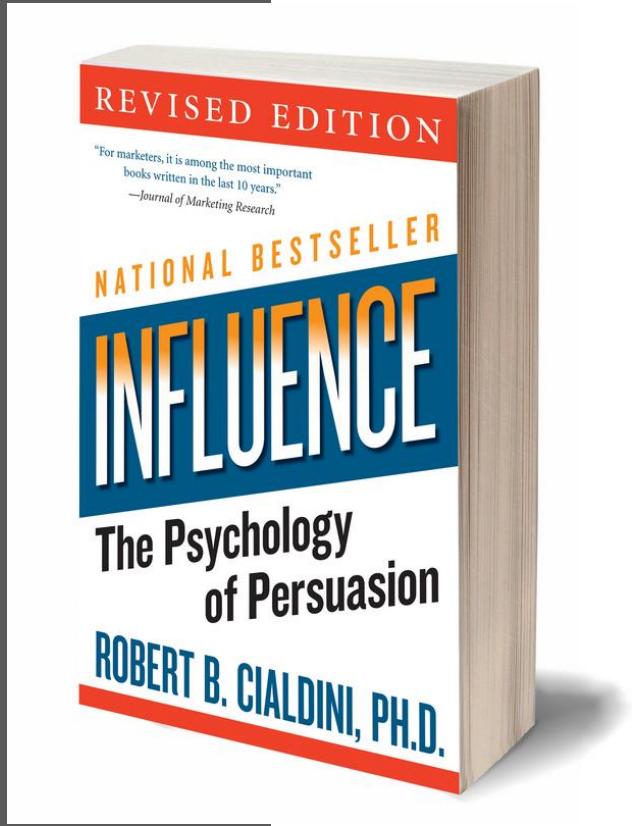


- Best practices & theories [1,2,3]
- Persuasion profiling techniques [4,5]
- Br-STPS (Brazilian Portuguese Susceptibility to Persuasion Scale)[6]

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 to 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[1]

Influence Principles[2]



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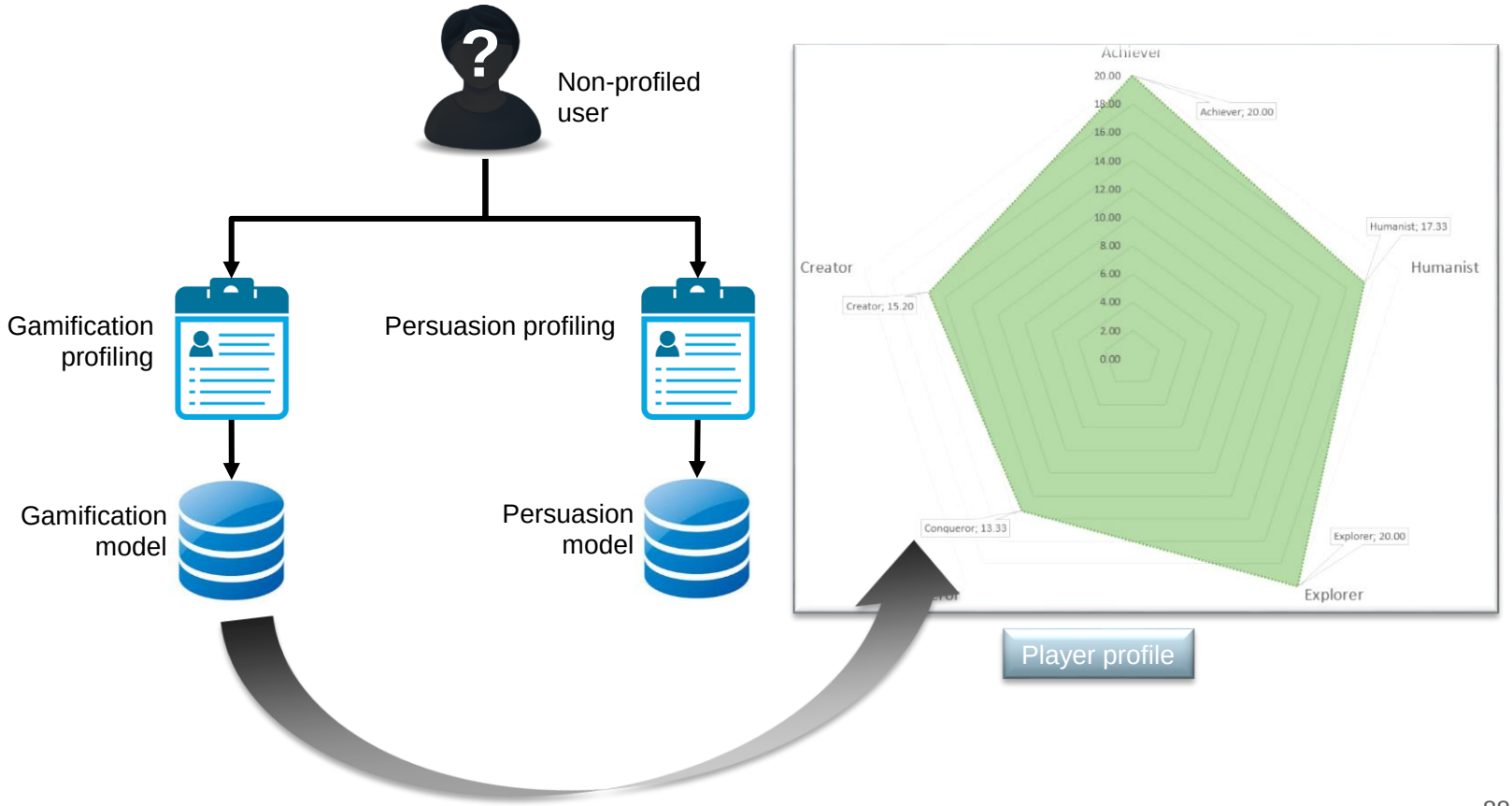

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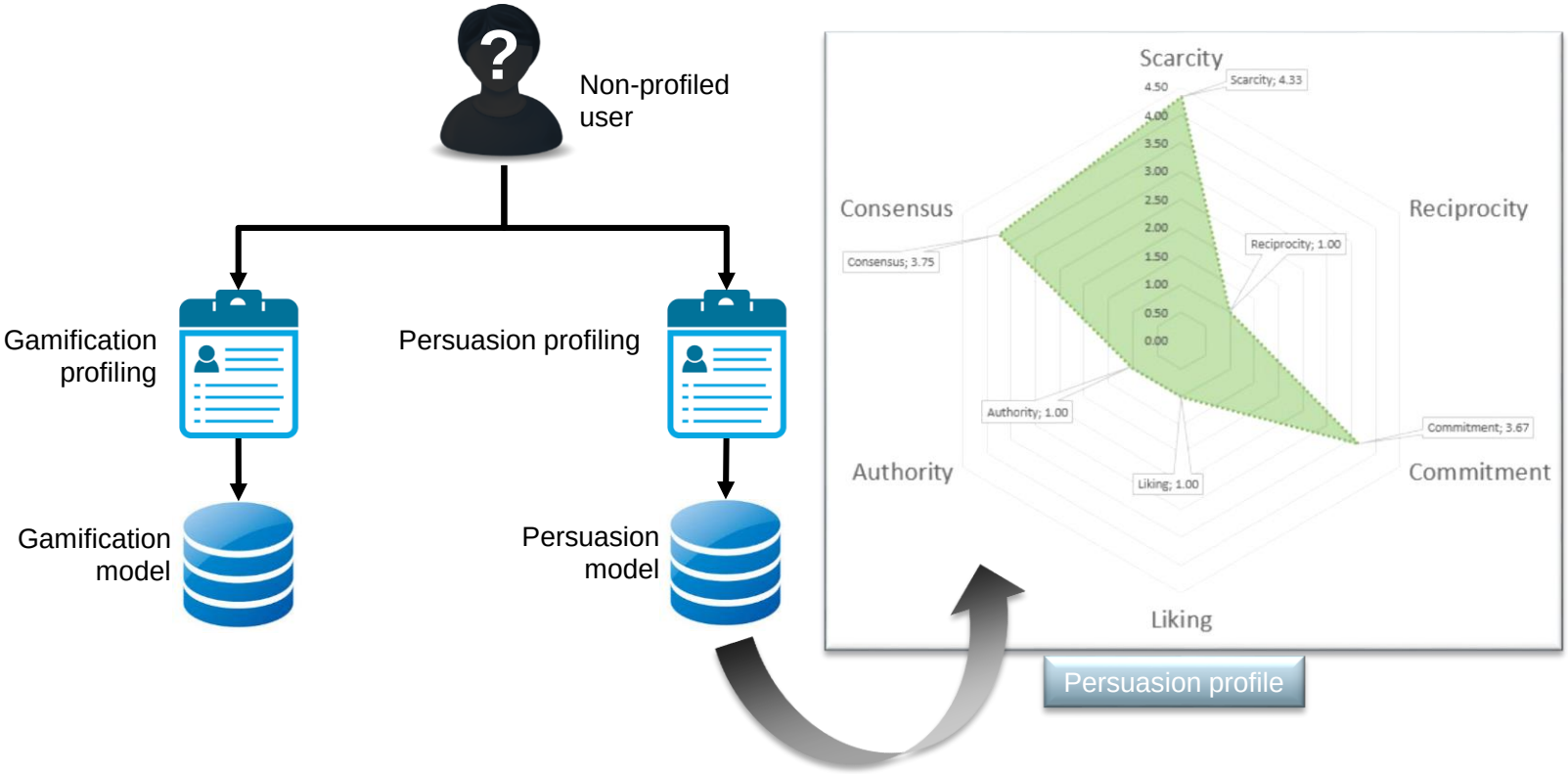

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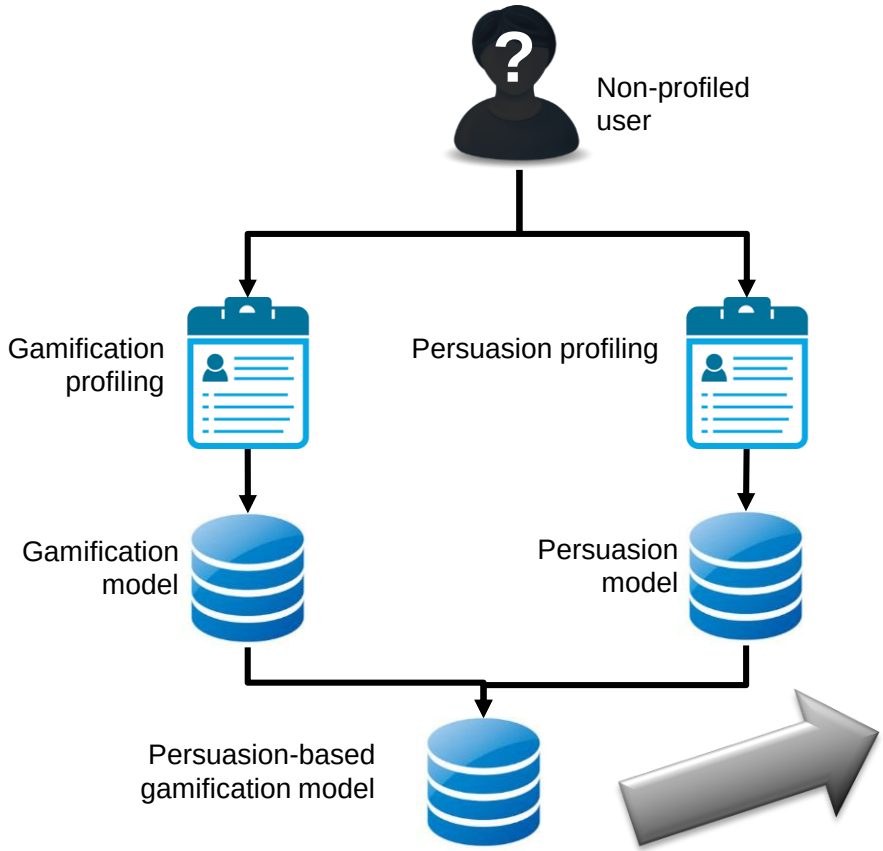

Is there a way to **tailor** influence principles to different player roles?

Tailoring influence principles to different player roles[1]

Best and worst influence principles, from left to right, the principles are listed according to the highest path coefficient (β) measured[1].

Player Role	Influence Principle	
	Best	*Worst*
Achiever	Reciprocity, Commitment, Scarcity	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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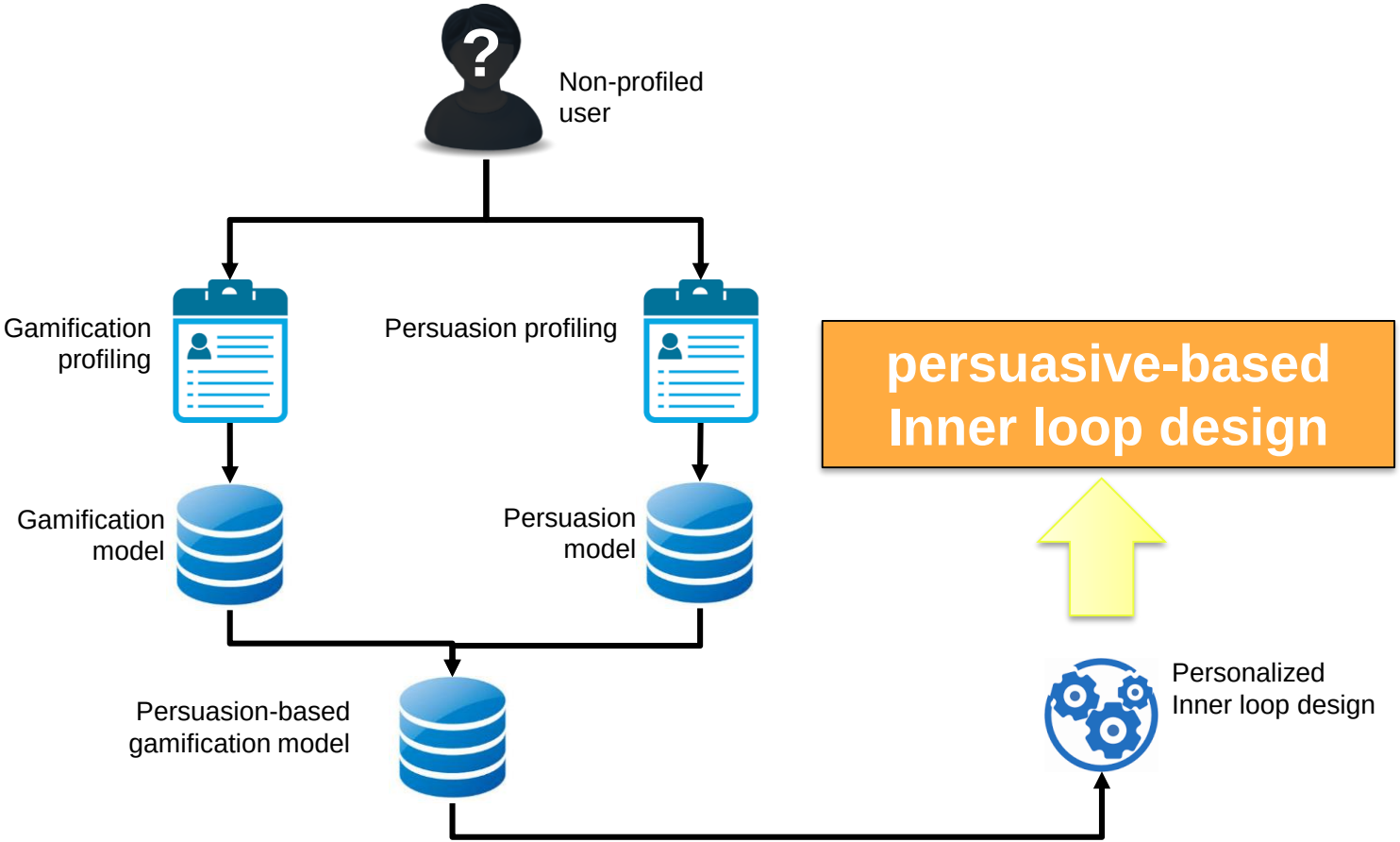

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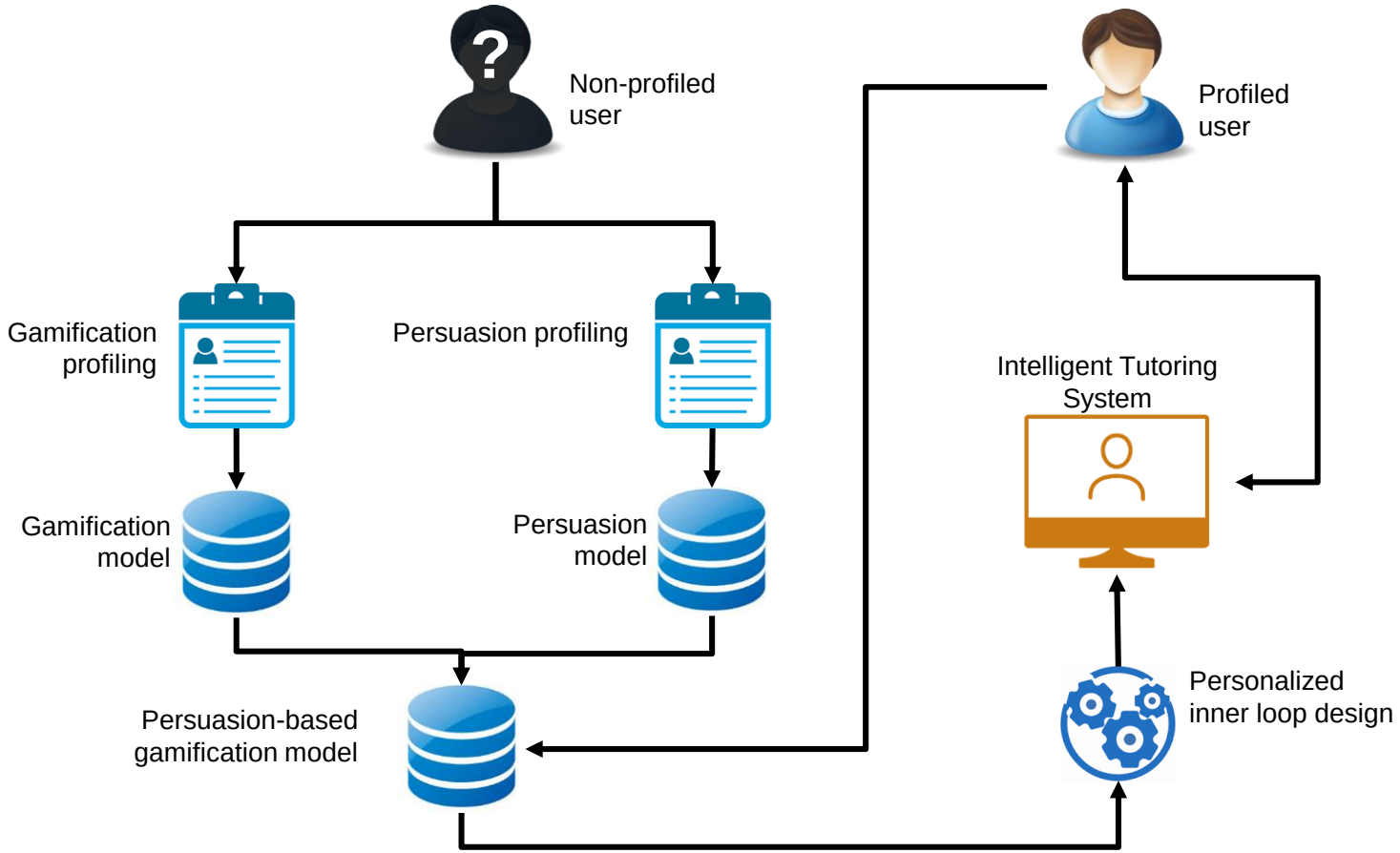

THANK YOU!

Intelligent Tutoring System: The importance of the Inner Loop

Prof. Seiji Isotani
University of Sao Paulo
sisotani@icmc.usp.br

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