International Conference NEW PERSPECTIVES in SCIENCE EDUCATION

Development of Computational Thinking through Adaptive Gamification and Learning Analytics to Enhance Science Education: A TPACK-Based Professional Development Program and Adaptive Environment Methodology

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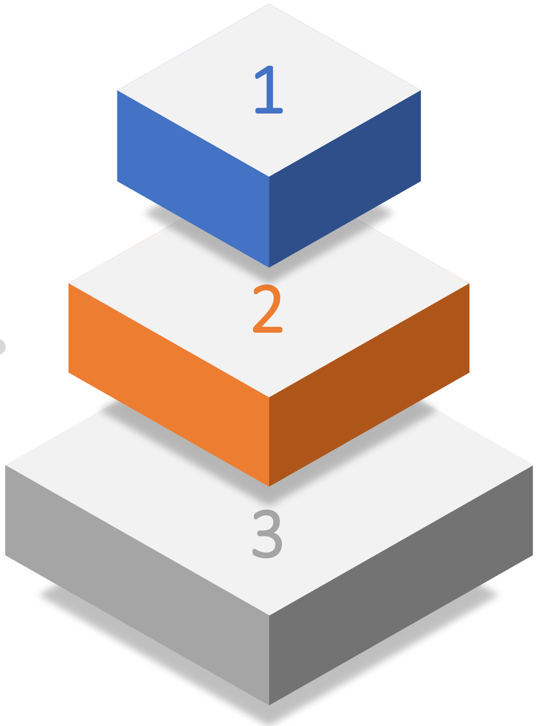
Content

What is Computational Thinking (CT)?

Structured approach

Fundamental problem-solving skill for the 21st century

Effective implementation of solutions by computer or human



(Wing, 2006)

The Imperative for Computational Thinking

Development of fundamental skills

Preparation for the Digital Society & Curriculum Integration into K-12 curricula globally

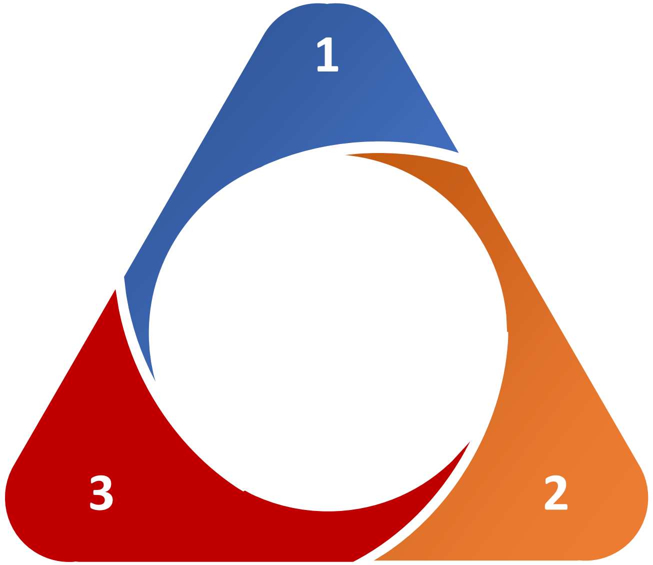
Beyond Programming

STEM Learning Support

(Vuorikari, et al., 2022; Wing, 2006; Zourmpakis, 2025)

The Importance of CT in Science Education

Enhancing Scientific Inquiry
Logical processes of CT elevate scientific methods



A Catalyst for Discovery
Learning how to observe, hypothesize, test, and revise.

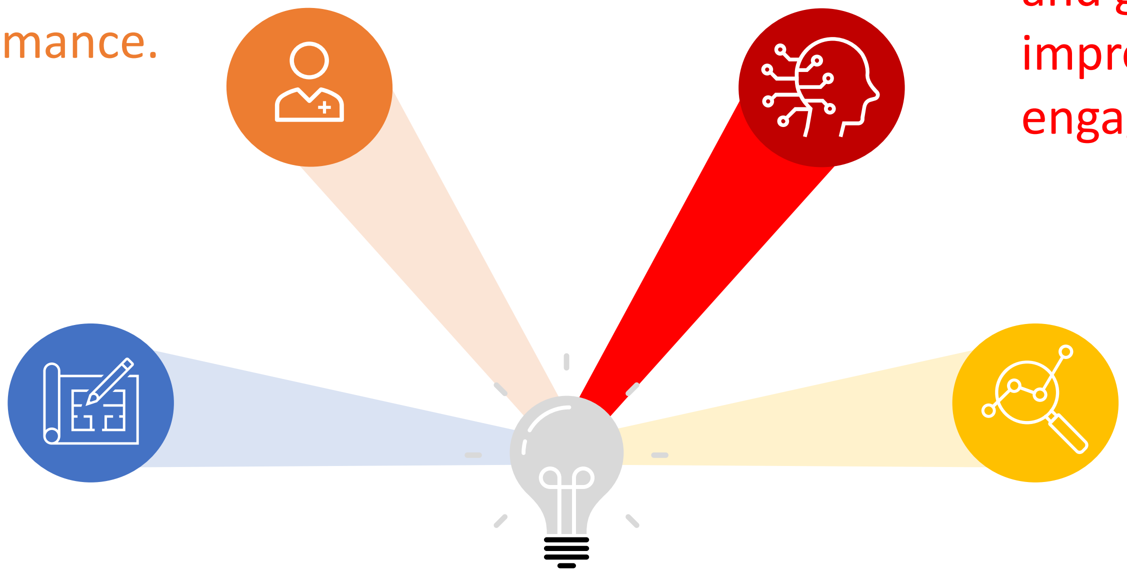
Transforming Science Classrooms
From passive memorization to active, analytical exploration.

Ogegbo & Ramnarain, 2022; Vuorikari et al., 2022)

The need for Adaptive Gamification

The need for Adaptive Learning:
Personalize educational paths and tailor content use to actual performance.

Benefits of Gamification:
Leverage motivational theories and gaming elements to improve motivation and active engagement.



The "One-Size-Fits-All" Issue:
Need to address diverse learning paces, habits, and individual needs

The Adaptive Gamification combination:
Dynamically alter both instructional content and motivational mechanics in real-time.

(O'Bannon & Thomas, 2015; Gligorea et al., 2023; Zourmpakis et al., 2023; Zourmpakis et al., 2024)

Teacher Education current state

Teacher CT Gap: Lack of prior CT knowledge and confidence

Evolving Roles: From traditional instructors to strategic facilitators

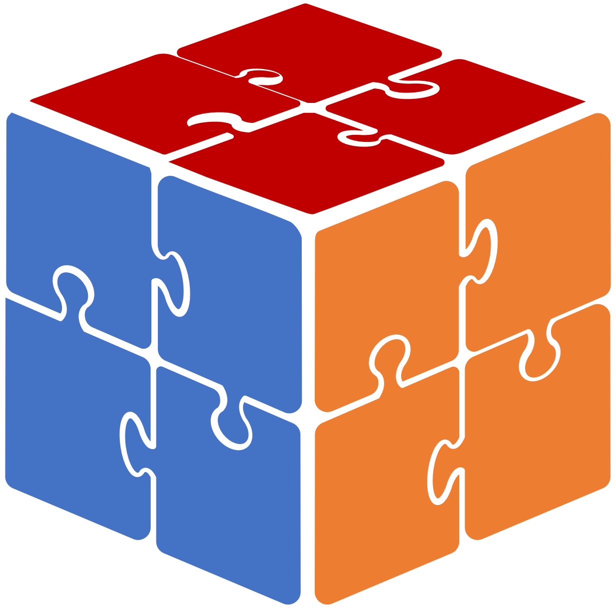
The potential of Data-Driven Support: Technical training is insufficient

Learning Analytics (LA): Provide accurate interventions without

(Herodotou et al., 2019; Torrance & Forde, 2017; Ung et al., 2022; UNESCO, 2008; Yang et al., 2025)

The Architectural Framework

2. Pedagogical strategy:
A combination of Problem-based and "Play-Modify-Create" approach



1. The Core Build:
A custom adaptive gamification environment

3. The Learning Analytics System:
A parallel Learning Analytics dashboard collects real-time data

(Ogegbo & Ramnarain, 2022; Papadakis et al., 2024; Zourmpakis et al., 2023)

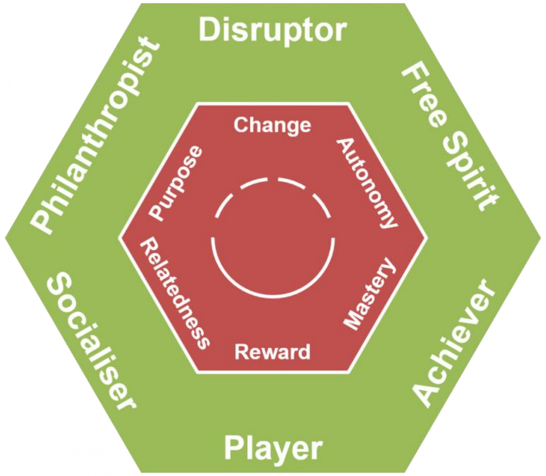
Initialization and Hexad Typology

Initialization: Users complete a validated 24-item questionnaire

Categorization: dominant player type and secondary traits

Hexad user types:

- ✓ *Achievers:* Competence (progress bars, mastery badges)
- ✓ *Players:* Extrinsic rewards (points, virtual currency)
- ✓ *Philanthropists:* Purpose (helping NPCs, unlocking world content)
- ✓ *Disruptors:* Change (testing boundaries, non-linear paths)
- ✓ *Socializers:* Relatedness (NPC interactions, narrative).
- ✓ *Free Spirits:* Autonomy (exploration, self-directed discovery).



(Zourmpakis et al., 2023)

Dynamic Adaptation Process

1

Layer 1: Initial Configuration:
Interface and rewards are set immediately based on the dominant Hexad type (e.g., badges vs. minimal UI).

2

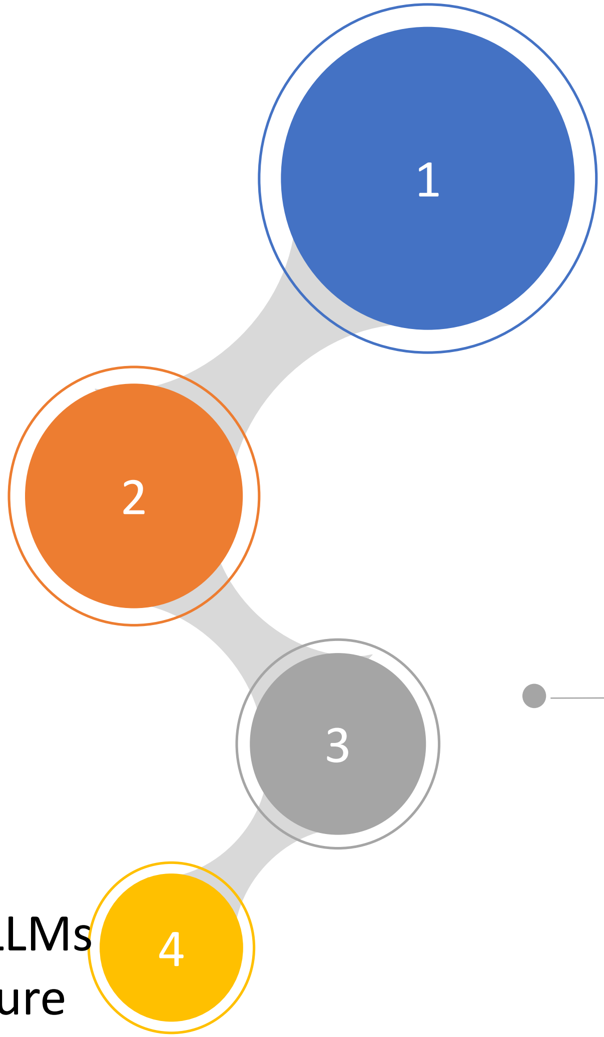
Layer 2: Run-Time Tracking:
Tracks continuously the time spent, mistakes made, difficulty preferences, and answers to AI NPCs

3

Pacing and game elements shifts:
Game pacing and game elements change dynamically based on performance and choices

(Zourmpakis et al., 2023)

The Innovative Role of AI NPCs



Intelligent Scaffolds

Moving beyond static dialogue trees to natural, dynamic conversations bound by scenario scripts.

Dual Functions

Assessors: Evaluating user solutions logically.

Feedback Providers: Offering natural language guidance and hints.

Technical Integration:

Currently utilizes the Gemini 2.5 Flash model via API.

Future Security Plans:

Transitioning to locally hosted open-source LLMs (e.g. DeepSeek, Qwen 2.5, Gemma 2) to ensure strict data privacy and sovereignty.

(Campitiello et al., 2024)

Linking CT to Science Education 1/2

General Curriculum direction:
Conceptual tasks unrelated to programming, transitioning to explicit scientific applications.

Introductory Task:
"Peanut Butter and Jam Sandwich" activity with an AI NPC to establish importance of CT and algorithmic thinking.

Module 1 - Abstraction:
CT Task: Planning a party by filtering irrelevant details.

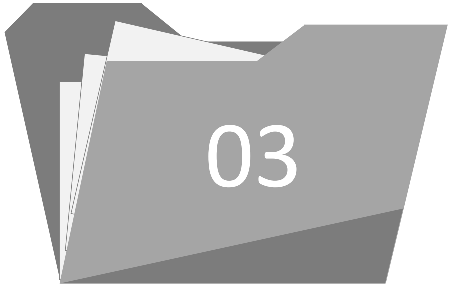
Science Link: Using standard abstract symbols in electrical circuit design to remove visual noise.

Module 2 - Decomposition:
CT Task: Breaking down a complex treasure hunt route into steps.

Science Link: Troubleshooting a broken mechanical toy by testing individual parts.

(Zourmpakis, 2025; Ng et al., 2021)

Linking CT to Science Education 2/2



Module 3 - Pattern Recognition:

CT Task: Identifying visual and logical patterns in puzzles.

Science Link: Analyzing shadow lengths to map solar movement, or testing materials with magnets to identify attraction patterns.

Module 4 - Algorithmic Thinking:

CT Task: Describing morning routines or debugging recipes using strict "if-then" logic.

Science Link: Scientific experimental design (e.g., isolating a single variable, like ramp angle, to ensure valid testing of a car's speed).

(Zourmpakis, 2025; Ng et al., 2021)

The Learning Analytics Dashboard

Real-Time Educator Empowerment:
The instructor accesses live data during gameplay, visualizing progression, mistakes, and dominant player types.

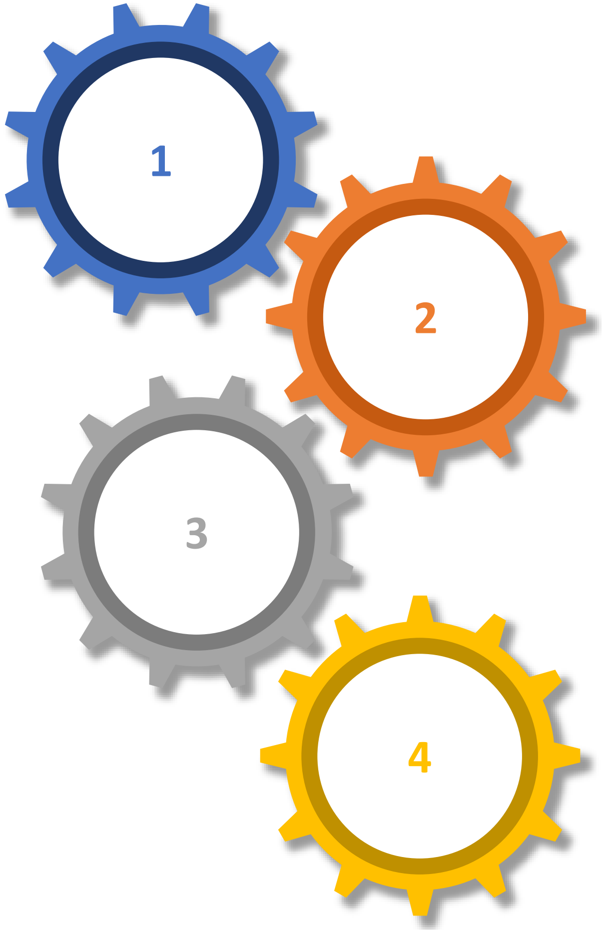
Actionable Insights:
Facilitates immediate broad or individualized interventions.

Technical Implementation:
Client-Server-Client model using the Firebase Unity SDK to sync data to an instructor’s tablet UI seamlessly.

Tailored Communication:
Allows educators to adjust in-person language based on class profile.

(Herodotou et al., 2019; Wong et al., 2019; Yang et al., 2025)

TPACK-Based Professional Development



Holistic Competence:

Grounded in the TPACK framework to move teachers beyond isolated technical training.

The Pedagogical Model:

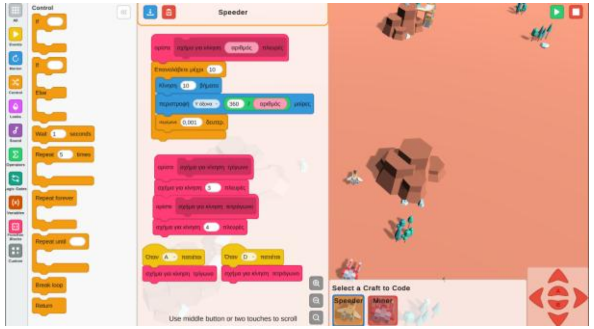
Problem-based learning & "To Play, To Think, To Code, To Link"

The Transition:

Moving from the guided gamified app to an open, custom block-based coding interface (similar to Scratch).

The Final Link:

Teachers analyze pre-built programs with issues, fix "bugs," create working logic, and design a practical science lesson based on these concepts.



(Jimoyiannis, 2010; Kong & Lai, 2022; Zourmpakis et al., 2022)

Conclusions & Future Directions

Modernizing Teacher Education

A comprehensive blueprint combining adaptive technologies with robust pedagogical strategies (TPACK).

Fostering Engagement

Utilizing the Hexad model, AI NPCs, and LA reduces cognitive load and tailors the experience for pre-service teachers.

The Central Role of the Educator

Technology enables adaptation, but the instructor remains pivotal in guiding pedagogy.

Next Steps

The application is currently in alpha; future research will focus on empirical validation to assess its exact impact on teacher self-efficacy.

(Papadakis et al., 2024; Elmaadaway & Abouelenein, 2023)

Thank you very much for your attention!

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