Assessment for Learning in Informatics education: The CAIR framework and a STEAM-based application

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Abstract: *Competency-based Informatics education requires assessment practices that support iterative learning, problem-solving, and learner self-regulation; however, assessment often remains predominantly summative and weakly integrated with instruction. This paper presents a CAIR-oriented approach to operationalising Assessment for Learning in upper secondary Informatics education. Rather than introducing additional assessment instruments, the CAIR framework embeds formative assessment directly into instructional design by aligning learning tasks, feedback, and reflection with Informatics-specific competencies. Using a design-based, illustrative perspective, the study examines an authentic project-based learning scenario involving C/C++ programming and microcontroller-controlled smart systems. A parking system with a servo-controlled barrier is analysed to demonstrate how assessment evidence emerges through iterative cycles of design, testing, debugging, and reflection. The analysis highlights CAIR's capacity to support coherent alignment among competencies, learning activities, and formative assessment while remaining adaptable to practical classroom constraints.*

Keywords: Assessment for Learning, Informatics education, Competency-based assessment, CAIR framework, Project-based learning.

1. Introduction

The increasing centrality of digital technologies in contemporary society has intensified the need for Informatics education to move beyond content transmission toward the systematic development of competencies such as algorithmic reasoning, problem solving, adaptability, and self-regulated learning. In response, many curricula have adopted a competency-based orientation; however, assessment practices in Informatics often remain predominantly summative and product-focused. This misalignment limits the capacity of assessment to support learning processes that are inherently iterative, exploratory, and reflective, particularly in programming- and system-oriented contexts (Gutu, 2025a).

Within this landscape, Assessment for Learning (AfL) has emerged as a promising approach for repositioning assessment as an integral component of instruction (Cambridge Assessment International Education, n.d.; Carless, 2017; Gutu, 2022; Arnold & Willis, 2024). AfL emphasises formative feedback, learner involvement, and the purposeful use of assessment information to guide learning; however, despite its well-documented pedagogical value, its implementation in

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Informatics education remains challenging and often insufficiently aligned with targeted competencies (Gutu, 2022).

This paper contends that addressing this challenge requires not only the adoption of AfL principles but also a coherent pedagogical framework that systematically embeds formative assessment within instructional design. The study introduces and applies the CAIR framework (Constructivist-Adaptive-Integrative-Reflective) as a design-oriented approach for operationalising AfL in Informatics education, aligning learning activities, feedback processes, and reflective practices with competency development without introducing additional assessment instruments or parallel evaluation structures (Gutu, 2025c).

The purpose of this paper is to examine how CAIR-oriented AfL can be operationalised and enacted in upper secondary Informatics education through authentic, practice-based learning scenarios. Rather than evaluating learning outcomes through experimental comparison, the study adopts a design-based, illustrative approach that foregrounds pedagogical coherence, alignment, and feasibility.

Accordingly, the paper pursues the following objectives:

1. to articulate a coherent theoretical foundation for AfL in Informatics education, grounded in competency-based pedagogy and aligned with the epistemological characteristics of the discipline;
2. to describe how the CAIR framework operationalises AfL by embedding constructivist tasks, adaptive feedback, integrative learning design, and reflective practices within instructional planning;
3. to illustrate this operationalisation through an authentic application scenario involving project-based, technology-rich Informatics learning;
4. to analyse practical challenges and considerations associated with implementing CAIR-oriented AfL in formal educational settings; and
5. to discuss the pedagogical implications of using CAIR as a unifying framework for assessment-driven competency development in Informatics education.

By addressing these objectives, the paper contributes to ongoing discussions on transforming assessment practices in Informatics education and offers a coherent model for aligning curriculum, instruction, and assessment to support sustainable competency development.

2. Theoretical framework

The evolution of Informatics education toward a competency-based paradigm necessitates a corresponding transformation in assessment practices. Traditional assessment models, typically associated with Assessment of Learning, prioritise summative judgments of performance and tend to emphasise final products over learning processes (Azevedo, 2020; Gutu, 2022; Khiat & Vogel, 2022). While such approaches provide standardised measures of achievement, they offer limited support for the development of complex Informatics competencies such as algorithmic reasoning, problem decomposition, adaptability, and metacognitive regulation (Hong, 2020; Gutu, 2023). As a result, assessment risks becoming disconnected from instruction and learning, particularly in contexts where iterative problem solving, system modelling, and conceptual understanding are essential (Gutu, 2022, 2023; Revati, 2024).

In contrast, AfL positions assessment as an integral and continuous component of the learning process (Gutu, 2022). AfL emphasises formative feedback, active learner involvement, and the use of assessment information to foster self-regulated learning and to guide subsequent learning actions (Wirth & Leutner, 2008; Khiat & Vogel, 2022; Adler et al., 2025). Within Informatics education, this perspective aligns with the discipline's epistemological foundations, particularly in programming- and system-oriented contexts characterised by iterative cycles of hypothesis, implementation, testing, and refinement. Accordingly, effective assessment should support these cycles by clarifying learning goals, providing timely feedback, and promoting self-regulated learning.

A core requirement of AfL is the functional alignment between curriculum objectives, instructional activities, and assessment strategies (Gutu, 2022; Arnold & Willis, 2024). Research in instructional design and competency-based education highlights that learning outcomes are most effectively achieved when assessment criteria are transparent, coherent across tasks, and explicitly connected to intended competencies (Burlacu, 2021; Gutu, 2025b; Cheng & Huang, 2025). In Informatics education, such alignment enables assessment to capture not only solution correctness but also reasoning, strategic decision-making, and conceptual transfer. Furthermore, formative practices - such as self- and peer assessment and descriptive feedback - are most effective when systematically embedded in instructional design rather than implemented as isolated techniques (Filgona et al., 2020; Gutu, 2023; Revati, 2024).

Metacognition and self-regulation represent core dimensions of AfL. In Informatics, where problem solving involves uncertainty, multiple solution pathways, and increasing abstraction, learners' capacity to plan, monitor, and evaluate their learning is critical (Gutu, 2022, 2025b). AfL fosters metacognitive development by promoting reflection on strategies, evaluation against explicit criteria, and informed regulation of subsequent learning, positioning assessment as a driver of internal regulation (Ku & Ho, 2010; Hong, 2020; Gutu, 2023).

Within this theoretical landscape, the CAIR educational framework provides a coherent pedagogical model for operationalising Assessment for Learning in Informatics education. Rather than positioning assessment as an external control mechanism, CAIR embeds formative assessment functions directly within instructional design (Gutu, 2025c). Each dimension of the framework corresponds to a core requirement of AfL and addresses a distinct aspect of competency development.

The constructivist dimension foregrounds active knowledge construction through authentic tasks (Gutu, 2025a, 2025c) that engage learners in algorithmic reasoning, debugging, and problem solving. The adaptive dimension emphasises differentiated feedback and instructional pacing, allowing assessment to respond to learners' evolving levels of understanding and to support progression toward increasing task complexity. The integrative dimension ensures coherence across tasks, topics, and learning contexts, facilitating the transfer of Informatics competencies across projects and interdisciplinary (STEAM-related) activities. Finally, the reflective dimension emphasises self-regulation by embedding self-assessment and reflective practices that enable learners to monitor progress, evaluate strategies, and assume responsibility for learning decisions.

Figure 1 synthesises this theoretical framework by illustrating the alignment between CAIR dimensions, core Assessment for Learning functions, and illustrative examples from Informatics education. The figure highlights AfL as an emergent property of pedagogical design, arising from the systematic interconnection of learning activities, feedback mechanisms, and reflective practices.

CAIR dimensions	Assessment for Learning Function	Example in Informatics
Constructivist	Active knowledge construction	Algorithmic tasks, debugging
Adaptive	Differentiated feedback	Task level and complexity, learning pace
Integrative	Cross-task coherence	Projects, STEAM Links
Reflective	Self-regulation	Self-assessment, journals

Figure 1. Alignment between CAIR dimensions, Assessment for Learning functions, and illustrative examples in Informatics education

By embedding Assessment for Learning within the CAIR framework, assessment is reconceptualised as a continuous process that actively shapes learning trajectories rather than a terminal act of measurement. This perspective underpins the subsequent sections, which examine the operationalisation of CAIR-oriented AfL through authentic, practice-based Informatics learning scenarios and their implications for competency development.

3. Operationalising assessment for learning through the CAIR framework

Building on the theoretical framework, this section focuses on the practical operationalisation of AfL in Informatics through the CAIR framework by designing learning tasks that integrate instructional and assessment purposes. In Informatics, such tasks emphasise algorithmic reasoning, problem-solving, and iterative refinement, allowing assessment to emerge naturally from students' engagement with programming and system design activities. Each task is associated with clear performance criteria, ensuring transparency and enabling learners to interpret feedback in relation to expected competencies (Gutu, 2023).

The CAIR framework supports the adaptive use of assessment information by allowing task complexity, pacing, and feedback to be adjusted in response to learners' progress (Gutu, 2025a). Formative feedback functions as a continuous process that informs both instructional decisions and learner actions, guiding learning trajectories rather than merely documenting achievement, an approach particularly suited to Informatics contexts characterised by heterogeneous learner profiles and iterative problem-solving processes.

Integration across tasks, learning contexts, and STEAM domains represents another core operational principle. Assessment criteria are applied consistently across activities and interdisciplinary projects (Burlacu & Irimiciuc, 2018; Cheng & Huang, 2025), ensuring coherence in competency development and supporting learners' ability to transfer algorithmic reasoning, system thinking, and computational problem-solving skills across scientific, technological, engineering, artistic, and mathematical contexts. This integrative STEAM-oriented approach reinforces the perception of Informatics as a coherent and generative discipline.

Reflective practices are systematically embedded to support learner agency and self-regulation. Through self-assessment and guided reflection, learners analyse their strategies, evaluate system behaviour, and plan subsequent learning actions (Khiat & Vogel, 2022), while predominantly descriptive, forward-oriented feedback fosters improvement and metacognitive awareness (Gutu, 2022, 2023).

By aligning constructivist learning tasks, adaptive feedback mechanisms, integrative task design, and reflective practices within a unified structure, the CAIR framework provides a coherent operational model for implementing Assessment for Learning in Informatics education, enabling assessment to function as an integral component of instructional design rather than as a separate evaluative stage.

4. Application scenarios in Informatics education

To illustrate the coherent integration of AfL within the CAIR framework, this section presents a representative application scenario derived from an interdisciplinary project implemented in upper secondary Informatics education. The projects were conducted within the formal curriculum and focused on the design and implementation of functional smart systems controlled through C/C++ programming and microcontroller-based platforms.

The instructional activities described in this study were implemented within the framework of the project *"STEAMing Across Borders: Empowering Young Women from the Republic of Moldova in Science"*, while remaining fully integrated into the formal upper secondary Informatics curriculum. Within this context, students developed complete functional systems, including programmable traffic lights, radar-based object-detection systems, parking systems with servo-controlled barriers, smart houses with anti-theft mechanisms, password-protected access systems, and digital calculators. The design and implementation of these systems required the cumulative application of Informatics concepts across multiple instructional sessions, fostering knowledge transfer, higher-order problem-solving, and structured reflective practice.

To exemplify this approach, this section examines a parking system with a servo-controlled barrier, developed and simulated on an Arduino Uno platform within the Tinkercad hardware simulation environment. The system models an access-control scenario in which vehicle presence is detected by an HC-SR04 ultrasonic distance sensor, and barrier actuation is controlled by a servo motor driven by the microcontroller. The experimental setup comprises an Arduino Uno board, an ultrasonic distance sensor, a servo motor, and a breadboard for prototyping electrical connections, enabling distance-based decision logic and actuator control. The complete wiring scheme and component configuration are illustrated in Figure 2.

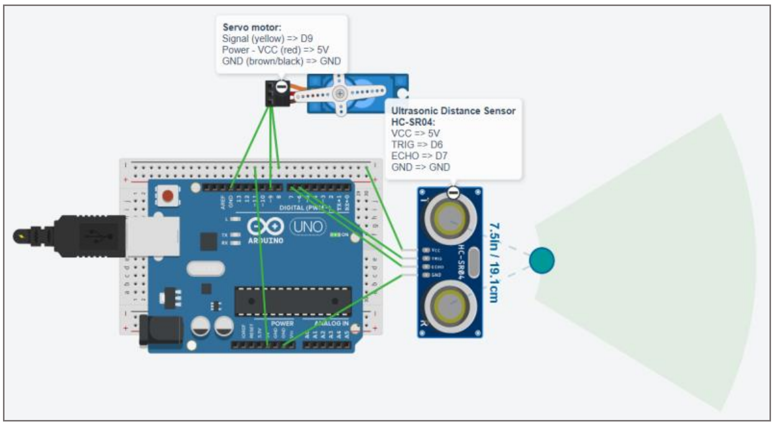

Figure 2. Hardware configuration of the ultrasonic distance–based servo control system simulated in Tinkercad

The servo motor is connected to the Arduino Uno via the digital pin D9, configured for Pulse Width Modulation (PWM), while the HC-SR04 ultrasonic sensor is interfaced using digital pin D6 for the trigger signal and digital pin D7 for the echo signal. Both components are powered through the 5V and GND pins of the Arduino board, ensuring compatibility with low-cost educational hardware while providing sufficient accuracy for distance-based control tasks.

The HC-SR04 ultrasonic sensor determines distance by emitting an ultrasonic pulse and measuring the time interval between the pulse and the reflected echo from the target object. The measured echo pulse duration is then converted into distance using the standard time-of-flight relation expressed in Equation (1):

$$d_{cm} = \frac{t_{\mu s}}{58} \tag{1}$$

where d denotes the distance in centimetres and t represents the echo pulse duration measured in microseconds.

Based on the measured distance, the system controls the servo motor's angular position to emulate a physical parking barrier. To ensure stable operation and to mitigate rapid oscillations caused by minor sensor noise, a hysteresis-based control strategy is employed. When an object is detected within 15 cm, the servo rotates to 90°, corresponding to the open barrier state. Once the object moves beyond 25 cm, the servo returns to 0°, representing the closed position. The intermediate range between these thresholds suppresses repeated state transitions and contributes to robust and reliable system behaviour.

Distance measurements are performed at fixed 80-millisecond intervals using a non-blocking timing mechanism based on the millis() function. This approach maintains system responsiveness and facilitates future extensibility, such as the integration of additional sensors or communication modules. The control algorithm is implemented in a modular C/C++ structure, with a clear separation between sensor acquisition, decision logic, and actuator control. Debugging and display-related instructions are intentionally excluded, as the system operates autonomously without a visual interface.

To support transparency, reproducibility, and reflective learning, the Arduino C/C++ source code and the hardware simulation are provided as open-access digital artefacts. The source code is available via a public GitHub repository, while the hardware configuration and runtime behaviour can be explored through an interactive Tinkercad Circuits simulation; an overview of these resources is summarised in Table 1.

Table 1. Open-access digital artefacts supporting transparency and reproducibility

Digital artefact	**Supplementary material**
Arduino C/C++ source code (servo-controlled parking system)	GitHub repository Access link: https://github.com/mgutu/Tinkercad_Arduino_Programs/blob/main/Servo_Controlled_Parking_System
Hardware simulation (Arduino Uno parking system)	Tinkercad Circuits simulation Access link: https://www.tinkercad.com/things/fTyK0ReARBC-servo-controlled-parking-system?sharecode=kxInFwJr_YgmMqz3k5BvcoDzu_CNxbCjg8fK5tpG0yc

The parking system scenario enables an integrated assessment of student learning by aligning Informatics-specific competencies with the CAIR framework and Bloom’s taxonomy within a single coherent learning activity. Table 2 synthesises this alignment by mapping observable indicators that emerge directly from students’ design, implementation, and iterative refinement processes. Throughout the project, these processes were supported by structured teacher facilitation and AI-based chatbot assistance, which provided ongoing scaffolding and formative guidance aligned with the principles of Assessment for Learning.

Table 2. Integrated assessment framework for the ultrasonic parking system scenario

Assessment Dimension	**Indicators of Student Performance**
Informatics-Specific Competencies	Students correctly apply structured C/C++ syntax, implement conditional logic and state management, interface sensors and actuators through digital I/O, and translate real-world constraints into algorithmic solutions.
CAIR – Constructivist	Knowledge is actively constructed through hands-on experimentation, code modification, and debugging of sensor–actuator interactions.
CAIR – Adaptive	Students adjust threshold values, timing intervals, and logic structures in response to system behaviour and feedback obtained during testing.
CAIR – Integrative	The task integrates programming, electronics, and physics concepts (ultrasonic wave propagation) with real-world system modelling to deliver a coherent solution.
CAIR – Reflective	Learners analyse system stability, justify the use of hysteresis, and reflect on alternative control strategies to improve reliability.
Bloom's Taxonomy	Learning progresses from understanding sensor principles (Understanding), implementing control logic (Applying), analysing system behaviour and stability (Analysing), evaluating design choices such as threshold values (Evaluating), and designing a functional autonomous system (Creating).

Through this scenario, assessment becomes inseparable from learning itself: students demonstrate competence not only through the successful development of a functional artefact, but also through the reasoning, adaptation, and reflection embedded in the development process. This illustrates how CAIR-oriented Assessment for Learning can be effectively operationalised in Informatics education through authentic, technology-rich tasks that integrate guided instruction, adaptive support, and reflective practice.

5. Challenges and practical considerations

The operationalisation of CAIR-oriented AfL in upper secondary Informatics education entails several pedagogical and practical challenges. A primary consideration concerns time management within formal curricula, as formative assessment grounded in iterative design, testing, feedback, and reflection often requires a different allocation of instructional time than conventional task-submission approaches. This requires instructional planning to prioritise conceptual understanding, algorithmic reasoning, and systems thinking while maintaining alignment with curricular requirements.

A further challenge concerns the evolving instructional role of the teacher, who functions less as an evaluator of final outputs and more as a facilitator of learning processes through formative feedback and adaptive guidance. In Informatics contexts involving integrated hardware and software components, this role demands both strong subject-matter expertise and the capacity to manage differentiated learning trajectories. Although resource availability may affect implementation, the core principles of CAIR and AfL remain transferable through virtual simulations and software-based models.

Addressing this challenge requires a structured progression in teacher readiness rather than additional training. The CAIR framework builds on existing instructional practices by repositioning assessment within learning activities. Initial implementation may begin with a single unit or project, gradually expanding across modules or courses. Reusable assessment templates, transparent criteria, and guided reflection prompts support differentiated learning, while AI-assisted tools (e.g., formative feedback chatbots) can reduce organisational and cognitive load without compromising pedagogical intent.

Learner readiness influences effective enactment, as students may initially lack the metacognitive and self-regulatory skills required for reflective, feedback-driven learning. Gradual scaffolding of self-assessment and reflection is therefore essential to build assessment literacy and learner confidence, highlighting the need for contextual adaptation to ensure the sustainable integration of CAIR-oriented AfL within existing curricular and institutional constraints.

Within the CAIR framework, learner autonomy is viewed as a developmental outcome rather than a prerequisite. Initial stages rely on teacher-guided feedback, explicit criteria, and structured reflection to support students with limited self-regulation. As assessment literacy and confidence grow, scaffolding is gradually reduced, fostering independent decision-making and self-assessment.

6. Discussions

While no experimental comparison with a control group was conducted, the study does not seek to demonstrate statistical superiority over traditional instructional approaches. Instead, it provides a theoretically grounded, design-oriented illustration of how the CAIR framework can operationalise AfL in authentic Informatics contexts, emphasising coherence, alignment, and feasibility.

The application scenarios provide evidence of the educational value of the CAIR framework as an assessment-oriented instructional approach in Informatics education. The findings show that CAIR embeds formative assessment processes directly within authentic, technology-rich learning activities, positioning assessment as an integral component of instructional design.

A core contribution of the framework lies in integrating assessment into iterative cycles of design, implementation, feedback, and reflection, aligning with the iterative nature of Informatics learning. As demonstrated through the smart-system projects, this approach enables continuous, task-embedded feedback that informs learner decision-making and supports progressive competency development, thereby strengthening coherence between curricular objectives, instructional activities, and assessment criteria (Gutu, 2025b).

The discussion also highlights learner agency and self-regulation as central outcomes of CAIR-oriented AfL. Through structured reflection and self-assessment, learners actively monitor their progress and evaluate design choices, fostering metacognitive awareness and reflective judgment, which are essential for sustained learning in rapidly evolving technological domains (Azevedo, 2020; Hong, 2020; Gutu, 2023). Autonomy and self-regulation emerge progressively through intentional instructional design supported by guided reflection and descriptive feedback.

From a pedagogical perspective, CAIR provides a flexible and coherent structure adaptable to diverse Informatics contexts and resource conditions. Its effectiveness depends on intentional instructional design and teacher readiness, functioning as a guiding lens rather than a prescriptive model, and reinforcing assessment as a driver of learning and competency development through constructivist, adaptive, integrative, and reflective practices.

7. Conclusions

This study examined the operationalisation of Assessment for Learning in Informatics education through the CAIR framework, embedding formative assessment into instructional design. Addressing the misalignment between competency-based curricular objectives and predominantly summative assessment practices, the findings demonstrate how assessment can function as a continuous driver of learning.

Using a design-based illustrative approach, the study showed that CAIR-oriented AfL can be implemented without introducing additional assessment instruments or parallel evaluation structures. The project-based smart-system scenario illustrated how assessment evidence emerges through iterative cycles of programming, testing, debugging, and reflection, aligning Informatics-specific competencies with the CAIR dimensions and Bloom's taxonomy.

The findings further indicate that effective implementation depends on intentional instructional planning and contextual adaptation, particularly with respect to time constraints, resource availability, learner readiness, and the coexistence of formative and summative assessment systems. Therefore, the CAIR framework provides a coherent and adaptable model for aligning curriculum, instruction, and assessment in Informatics education, supporting sustainable competency development and learner self-regulation.

Future research may extend this work by examining the scalability of CAIR-oriented AfL across diverse educational contexts and by exploring its impact through longitudinal or comparative study designs. Such investigations could complement the present design-based contribution by providing additional empirical perspectives on learning outcomes and instructional effectiveness.

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