An interactive online trainer for primary school computer science education: Design, implementation, and theoretical foundations

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Abstract
This paper presents an interactive online trainer for primary school computer science education designed to address the challenges of introducing computational thinking and digital literacy skills to young learners. The system incorporates game-based learning, multimedia elements, and self-regulated learning principles to provide an engaging, accessible, and effective learning experience. The interactive online trainer features three main types of learning activities: image-text matching, puzzle assembly, and multiple-choice quizzes, which are designed to progressively build students' understanding of computer science concepts. The interactive online trainer has the potential to support the integration of computer science education into primary school curricula and promote early exposure to computational thinking and digital literacy skills.

Keywords
computer science education, educational technology, game-based learning, interactive learning, multimedia learning, primary education, self-regulated learning

1. Introduction

Computer science (CS) education has become increasingly crucial, even at the primary school level [1, 2]. Exposing students to CS concepts and skills from an early age can foster computational thinking [3], problem-solving abilities, and digital literacy [4, 5]. Early introduction to CS has the potential to broaden participation in the field and promote equity by providing access to all students, regardless of their background [6]. As technology continues to permeate every aspect of our lives, it is essential to equip young learners with the knowledge and skills necessary to thrive in a technology-driven world [7, 8].

Despite the recognized importance of CS education, integrating it into primary school curricula presents several challenges. One major obstacle is the lack of qualified teachers with the necessary knowledge and skills to effectively teach CS concepts [9, 10]. Many primary school teachers do not have a background in CS and may feel unprepared or hesitant to teach the subject [11]. Additionally, there is often a shortage of age-appropriate learning resources and tools that cater to the developmental needs and capabilities of young learners [12]. Furthermore, finding ways to make CS concepts engaging, interactive, and accessible to children with diverse learning styles and backgrounds can be challenging [13].

Interactive online trainers offer a promising solution to address the challenges of introducing CS education in primary schools. These digital tools can provide an engaging and accessible platform for students to learn and practice CS concepts at their own pace [8, 14]. Interactive trainers can incorporate gamification elements, such as rewards and challenges, to motivate and engage young learners [15, 16]. They can offer immediate feedback and adapt to individual student's needs and progress [17]. Interactive

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online trainers can also support teachers by providing structured content, lesson plans, and resources, thus reducing the burden of lesson preparation and helping to bridge knowledge gaps [9, 18].

This paper presents the design and implementation of an interactive online trainer for primary school CS education. The main *objectives* of this research are:

1. To develop an interactive online trainer that effectively supports the learning of basic CS concepts for primary school students.
2. To describe the design principles, software architecture, and key features of the trainer.
3. To discuss the theoretical foundations underpinning the design of the trainer, including constructivist learning, game-based learning, multimedia principles, and self-regulated learning.
4. To outline a plan for evaluating the effectiveness of the trainer in terms of student learning outcomes, engagement, and motivation.

The following *research questions* guide this study:

RQ1: How can an interactive online trainer be designed to support the learning of CS concepts for primary school students?
RQ2: What are the key design principles and features that promote effective learning, engagement, and motivation in an interactive CS trainer?
RQ3: How can theories of learning and motivation inform the design of an interactive online trainer for primary school CS education?
RQ4: What are the potential implications of using an interactive online trainer for CS education in primary schools, and what are the limitations and future directions for research?

2. Theoretical background

Constructivist learning theory posits that learners actively construct knowledge through experiences and interactions with their environment [18, 19]. In this view, learning is not a passive process of information transmission but rather an active process of meaning-making and knowledge construction [20]. Interactive learning environments [21], such as online trainers, can support constructivist learning by providing opportunities for learners to actively engage with content, explore concepts, and receive feedback [22, 23].

Figure 1 illustrates the key principles of constructivist learning theory and how they can be applied in the design of interactive learning environments.

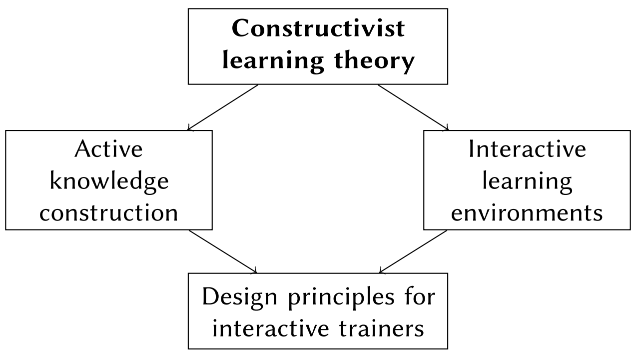

Figure 1: Constructivist learning theory and its application in interactive learning environments.

Game-based learning (GBL) and gamification have emerged as effective strategies for engaging and motivating learners [24, 25], particularly in the context of digital learning environments [7, 14]. GBL refers to the use of games specifically designed for educational purposes, while gamification involves the application of game elements and mechanics to non-game contexts [26, 27]. Both approaches can enhance learning experiences by providing challenges, rewards, and opportunities for active participation and problem-solving [16, 28].

Table 1 presents a comparison of game-based learning and gamification, highlighting their key characteristics and potential benefits for learning.

Table 1
Comparison of game-based learning and gamification.

	Game-based learning	**Gamification**
Definition	Games designed specifically for educational purposes	Application of game elements and mechanics to non-game contexts
Key characteristics	Fully-fledged games with learning content integrated into gameplay	Game-like features (e.g., points, badges, leaderboards) added to existing learning activities
Potential benefits	Engagement, motivation, active learning, problem-solving skills	Increased participation, motivation, and retention

Multimedia learning principles, derived from cognitive theories of learning, provide guidance for designing effective educational materials that combine words and visuals [28, 29]. These principles include [30]:

- The multimedia principle: students learn better from words and pictures than from words alone.
- The contiguity principle: corresponding words and pictures should be presented near each other in space or time.
- The modality principle: students learn better when words are presented as narration rather than on-screen text.
- The redundancy principle: students learn better from graphics and narration than from graphics, narration, and on-screen text.
- The coherence principle: learning is enhanced when extraneous material is excluded.

Figure 2 presents a visual representation of the multimedia learning principles and their application in the design of interactive learning materials.

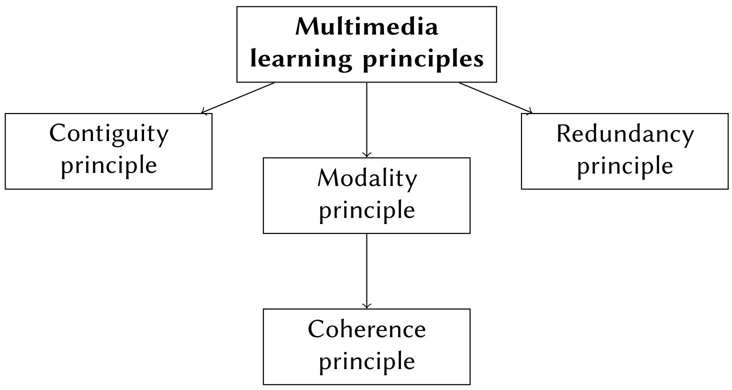

Figure 2: Multimedia learning principles and their application in interactive learning materials.

Self-regulated learning (SRL) refers to the process by which learners actively monitor, control, and regulate their cognitive, motivational, and behavioural processes to achieve their learning goals [23]. SRL is crucial for effective learning in interactive environments, where students have greater control over their learning pace and process [20]. *Motivation* is a key component of SRL, as it drives learners to engage in and persist with learning activities [18].

Figure 3 illustrates the cyclical nature of self-regulated learning and the role of motivation in the process.

Designing effective educational software requires the integration of learning theories, instructional design principles, and user-centred design approaches [31, 32]. Key considerations include:

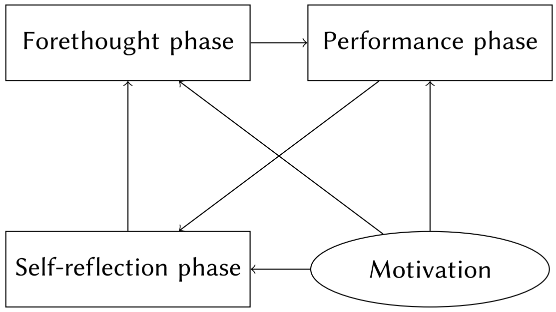

Figure 3: The cyclical nature of self-regulated learning and the role of motivation.

- Aligning learning objectives with content and activities
- Providing clear instructions and feedback
- Incorporating interactive and engaging elements
- Adapting to learners' needs and preferences
- Ensuring usability and accessibility

Table 2 presents a framework for designing effective educational software, highlighting the main stages and key activities involved in the process.

Table 2
A framework for designing effective educational software.

Design stage	Key activities
Analysis	Identify learning objectives, target audience, and constraints
Design	Develop instructional strategies, content, and user interface
Development	Implementation the software, integration content, and conduct testing
Implementation	Deploy the software, provide user support, and monitor usage
Evaluation	Assess learning outcomes, user satisfaction, and identify areas for improvement

3. Related work

Several interactive learning systems have been developed to support CS education at various levels, including primary schools. One notable example is the interactive multimedia package CITRA, designed to foster moral values and digital literacy among primary school students in Indonesia [33]. Another system, developed by Kaevikj et al. [34], focuses on teaching basic CS concepts through a combination of storytelling and interactive challenges. Guo and Wu [29] investigated the use of an iPad-based interactive learning application to support English language learning among rural primary school students in China, highlighting the potential of mobile technologies for CS education in resource-constrained settings.

Table 3 provides an overview of selected interactive learning systems for CS education, comparing their target audience, key features, and learning outcomes.

Numerous studies have investigated the effectiveness of game-based learning approaches for teaching CS concepts and skills. Kaldarova et al. [7] conducted an experimental study comparing the impact of a GBL intervention and traditional teaching methods on primary school students' learning of CS terminology. The results showed significant improvements in students' knowledge and motivation in the GBL group. Similarly, Alipova et al. [8] found that a custom-developed educational game significantly enhanced primary school students' memorization of CS terms compared to conventional instruction.

Research on multimedia design principles has provided recommendations for creating effective educational content. Chen et al. [28] investigated the impact of role-playing and simulation games

Table 3
Overview of selected interactive learning systems for CS education.

System	Target audience	Key features	Learning outcomes
CITRA [33]	Primary school students in Indonesia	Interactive multimedia, moral values education	Digital literacy, moral reasoning
Toby the Explorer [34]	Primary school students	Storytelling, interactive challenges	Basic CS concepts, problem-solving skills
iPad-based learning app [29]	Rural primary school students in China	Mobile-based interaction, English language learning	English knowledge construction, engagement

on primary school students' understanding of carbon footprint concepts, highlighting the importance of interactive and engaging multimedia elements. Friess et al. [35] explored the use of interactive storytelling and gamification to raise awareness of film design structures among primary school students, demonstrating the potential of multimedia-rich learning environments for fostering critical thinking and creativity.

Motivation is a crucial factor in the success of educational technology interventions. Li et al. [18] examined the influence of interactive learning materials on primary school teachers' self-regulated learning processes and learning satisfaction, highlighting the importance of intrinsic motivation and self-efficacy. Carroll et al. [16] evaluated the effectiveness of an interactive social-emotional learning program for primary school students, demonstrating the potential of gamified learning experiences to enhance motivation and engagement.

Table 4 summarizes the key motivational factors in educational technology and their impact on learning outcomes.

Table 4
Key motivational factors in educational technology and their impact on learning outcomes.

Motivational factor	Description	Impact on learning outcomes
Intrinsic motivation	Engaging in learning for its inherent enjoyment and satisfaction	Increased persistence, deeper learning, and creativity
Self-efficacy	Belief in one's ability to succeed in specific learning tasks	Higher performance, greater effort, and resilience
Autonomy	Sense of control and choice over one's learning activities	Enhanced motivation, engagement, and self-regulation
Relatedness	Feeling of connection and belonging within the learning environment	Improved participation, collaboration, and social support

4. System design and implementation

4.1. Design goals and principles

The primary goal of the interactive online trainer for primary school computer science education is to provide an engaging, effective, and accessible learning experience that aligns with the cognitive and developmental needs of young learners. The following design principles guided the development of the system:

- *A learner-centred design* was implemented, prioritizing the needs, preferences, and capabilities of primary school students [31].
- *Interactivity* was incorporated, promoting active learning, exploration, and experimentation [23].
- *Gamification features* were integrated to enhance motivation, engagement, and enjoyment [27].
- *Multimedia richness* was employed, combining text, images, animations, and other multimedia elements to support diverse learning styles and facilitate understanding [28].

- *Scaffolding* was provided, offering structured support and guidance to help learners progressively build their knowledge and skills [9].

4.2. Software architecture overview

The interactive online trainer is built using a client-server architecture, with the frontend implemented using web technologies (HTML, CSS, and JavaScript [36]). Figure 4 presents a high-level overview of the system's software architecture.

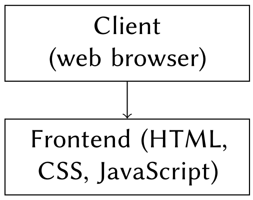

Figure 4: High-level overview of the system's software architecture.

4.3. User interface and interaction design

The user interface of the interactive online trainer is designed to be intuitive, visually appealing, and age-appropriate for primary school students. The system features three main types of learning activities: image-text matching, puzzle assembly, and multiple-choice quizzes.

4.3.1. Image-text matching activity

In this activity, students are presented with a set of images representing computer science concepts (e.g., hardware components) and corresponding text labels. The objective is to drag and drop the text labels onto the correct images, promoting visual recognition and vocabulary development. Figure 5 illustrates the user interface for the image-text matching activity.

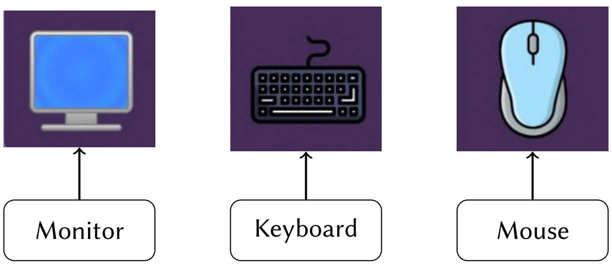

Figure 5: User interface for the image-text matching activity.

4.3.2. Puzzle assembly activity

The puzzle assembly activity challenges students to arrange a set of jumbled pieces to form a complete image related to a computer science concept. This activity aims to develop spatial reasoning, problem-solving skills, and conceptual understanding. Figure 6 depicts the user interface for the puzzle assembly activity.

4.3.3. Multiple-choice quiz

The multiple-choice quiz activity presents students with a series of questions related to computer science concepts, each accompanied by a set of possible answers. Students select the answer they believe to be

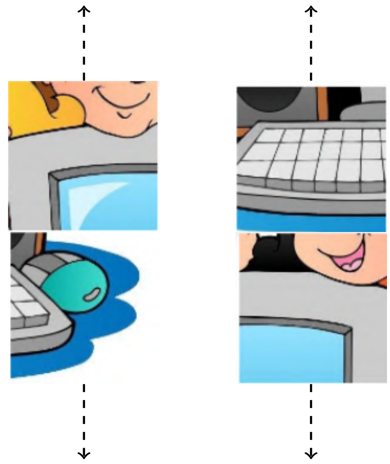

Figure 6: User interface for the puzzle assembly activity.

correct, receiving immediate feedback on their choice. This activity helps reinforce learning and assess comprehension. Figure 7 shows the user interface for the multiple-choice quiz activity.

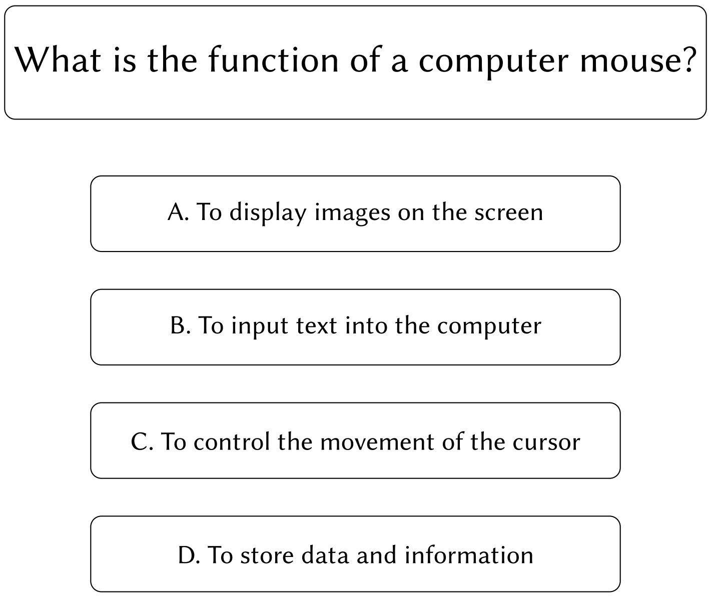

Figure 7: User interface for the multiple-choice quiz activity.

4.4. Content development and integration

The educational content for the interactive online trainer was developed in collaboration with primary school teachers and computer science education experts. The content is aligned with the learning objectives and standards of the primary school computer science curriculum, covering topics such as computer hardware, software, algorithms, and digital literacy [4].

The content is organized into modular units, each focusing on a specific concept or skill. Within each unit, the learning activities (image-text matching, puzzle assembly, and multiple-choice quizzes) are designed to progressively build on each other, providing a scaffolded learning experience [9].

4.5. Deployment and technical requirements

The interactive online trainer is deployed on a web server, such as Apache or Nginx, and can be accessed through a web browser on desktop computers, laptops, tablets, and smartphones. The system is designed to be responsive and compatible with modern web browsers, such as Google Chrome, Mozilla Firefox, and Apple Safari.

To ensure optimal performance and user experience, the following technical requirements are recommended:

- A reliable internet connection with a minimum bandwidth of 1 Mbps
- A device with a modern web browser and JavaScript enabled
- A screen resolution of at least 1280x1024 pixels

5. Planned evaluation

5.1. Research design and methodology

To evaluate the effectiveness of the interactive online trainer for primary school computer science education, a mixed-methods, quasi-experimental research design will be employed [37] after receiving ethical approval from the IRB. This approach combines quantitative and qualitative data collection and analysis to gain a comprehensive understanding of the system's impact on student learning, engagement, and motivation.

The study will involve two groups of primary school students: an experimental group using the interactive online trainer and a control group receiving traditional classroom instruction. The groups will be pre-tested to establish a baseline and post-tested to measure learning gains. Figure 8 illustrates the research design and methodology.

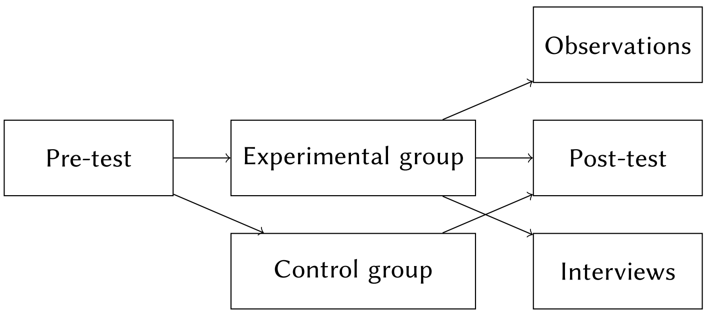

Figure 8: Research design and methodology for the evaluation of the interactive online trainer.

5.2. Participants and setting

The study will be conducted in three primary schools located in different regions of Ukraine to ensure a diverse sample of participants and students' safety. A total of 180 students (60 from each school) in grades 3-4 (ages 8-10) will be recruited to participate in the study. The students will be randomly assigned to either the experimental group or the control group within each school.

Table 5 presents the distribution of participants across the three schools and the experimental and control groups.

The study will take place during regular school hours. The experimental group will use the interactive online trainer in the school's computer lab, while the control group will receive traditional classroom instruction in their usual classroom setting.

Table 5
Distribution of participants across schools and experimental and control groups.

School	Experimental group	Control group	Total
School 1	30	30	60
School 2	30	30	60
School 3	30	30	60
Total	90	90	180

5.3. Data collection instruments

The following data collection instruments will be used in the study:

- A *pre-test and post-test* will be administered to all participants to measure learning gains in computer science knowledge. The test, consisting of multiple-choice and short-answer questions, will align with the primary school computer science curriculum [4].
- An *engagement and motivation survey* will be given to the experimental group to assess their engagement and motivation while using the interactive online trainer. The survey will include Likert-scale and open-ended questions adapted from validated instruments like the Intrinsic Motivation Inventory [18].
- *Semi-structured interviews* will be conducted with a subset of students from the experimental group (n=30, 10 from each school) to gather qualitative data on their experiences with the interactive online trainer. The interviews will focus on students' perceptions of usability, enjoyment, and the system's impact on their learning [23].
- *Classroom observations* will be carried out by researchers to document student behavior, engagement, and interactions with the interactive online trainer. Field notes and an observation protocol will be used to capture relevant data [20].

5.4. Analysis plan

The collected data will be analyzed using a combination of quantitative and qualitative methods to address the research questions and evaluate the effectiveness of the interactive online trainer.

For the quantitative data (pre-test and post-test scores, engagement and motivation survey responses), descriptive statistics (means, standard deviations) and inferential statistics (paired t-tests, independent t-tests, ANCOVA) will be used to compare the experimental and control groups and measure the impact of the intervention on student learning, engagement, and motivation [8].

For the qualitative data (semi-structured interviews, classroom observations), a thematic analysis will be employed to identify patterns and themes in students' experiences and perceptions of the interactive online trainer [9]. The qualitative findings will be used to triangulate and complement the quantitative results, providing a more comprehensive understanding of the system's effectiveness.

Table 6 summarizes the data sources, analysis methods, and expected outcomes of the evaluation.

Table 6
Data sources, analysis methods, and expected outcomes of the evaluation.

Data source	**Analysis method**	**Expected outcome**
Pre-test and post-test scores	Descriptive statistics, paired t-tests, independent t-tests, ANCOVA	Measure learning gains and compare experimental and control groups
Engagement and motivation survey	Descriptive statistics, independent t-tests	Assess engagement and motivation levels of the experimental group
Semi-structured interviews	Thematic analysis	Identify patterns and themes in students' experiences and perceptions
Classroom observations	Thematic analysis	Document student behaviour, engagement, and interaction with the system

6. Discussion

The development and evaluation of the interactive online trainer for primary school computer science education have several potential implications for the field. First, the system demonstrates the feasibility and effectiveness of using interactive, game-based learning approaches to introduce computer science concepts to young learners [7, 8]. Our interactive online trainer can help bridge the gap between traditional classroom instruction and the needs of digital native students [38].

Second, the interactive online trainer can serve as a model for designing and implementing educational technology interventions that are grounded in learning theories, such as constructivism, multimedia learning, and self-regulated learning [18, 28, 23]. The system's design principles and features, such as scaffolded learning activities, immediate feedback, and adaptive content, can inform the development of other educational software applications targeting primary school students [31, 32].

Finally, the interactive online trainer can support the integration of computer science education into primary school curricula by providing teachers with a valuable resource for classroom instruction and self-paced learning [4, 9]. The system can help address the challenges of limited teacher expertise and access to age-appropriate learning materials, thus promoting the widespread adoption of computer science education in primary schools [10, 12].

7. Conclusion

This paper presented the design, implementation, and planned evaluation of an interactive online trainer for primary school computer science education. The system aims to address the challenges of introducing computer science concepts to young learners by providing an engaging, accessible, and effective learning experience grounded in educational theories and best practices.

The interactive online trainer incorporates game-based learning, multimedia elements, and self-regulated learning principles to promote student engagement, motivation, and knowledge construction. The system features three main types of learning activities: image-text matching, puzzle assembly, and multiple-choice quizzes, which are designed to progressively build students' understanding of computer science concepts.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Drafting content, Text translation, Generate literature review, Grammar and spelling check, Content enhancement. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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