

Binary Spectrum: Inclusive CS Learning through Play

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ABSTRACT

Gender disparities and heterogeneous skill levels present significant challenges in middle-school computer science education. Binary Spectrum addresses these challenges as an educational iPad application designed to teach foundational computer science concepts through interactive mini-games, providing a gender-inclusive learning environment that accommodates different skill levels.

CCS CONCEPTS

• **Human-centered computing** → **Interactive systems and tools**; *User centered design*; • **Applied computing** → **Interactive learning environments**; *Computer-assisted instruction*.

KEYWORDS

Computer science education, educational games, gender inclusivity, adaptive learning, CS Unplugged, middle school education

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1 INTRODUCTION

Computer science (CS) as a school subject develops critical thinking and problem-solving skills when learners apply computational thinking concepts to real-world situations [7]. Despite this potential, current educational tools and approaches fail to engage learners' prior knowledge, motivation, and identity [3, 6]. This creates a need for innovative CS education tools that make abstract concepts accessible and relevant to diverse learners.

Two key challenges limit the effectiveness of CS education in middle schools. Gender inequality persists in CS participation, as girls disengage early due to a combination of missing role models and the design of educational technologies that often use examples preferred by boys, such as robots or cars [4, 5, 8]. These biases diminish long-term STEM engagement and reduce diversity in technical fields [6]. In addition, heterogeneous classrooms create

instructional challenges as learners progress at different paces and bring varied prior experiences to CS learning [3]. This diversity requires adaptive tools that accommodate different skill levels without excluding any individual learner.

Two pedagogical approaches shape the design of the tool. First, CS unplugged activities introduce core CS concepts without using computers [1]. These hands-on activities present topics such as binary representation, algorithms, and data encoding in age-appropriate ways that build foundational understanding. Second, Fullerton's virtuous cycle theory highlights that media created by and for women can sustain female engagement over time [2]. This theory supports the inclusion of diverse representation, storytelling, and artistic design in CS educational tools.

2 BINARY SPECTRUM

To address the challenges, this paper introduces Binary Spectrum, an educational iPad application designed to teach foundational CS concepts through engaging mini-games. By making these concepts more tangible and enjoyable, Binary Spectrum provides a welcoming entry point into CS for middle school learners who may not feel reflected in traditional programming environments.



Figure 1: Main menu of Binary Spectrum.

Binary Spectrum employs a gender-sensitive approach through its visual style, character design, and narrative framing to appeal to learners of all genders. It supports heterogeneous classrooms through feedback mechanisms, optional guidance, and replayable challenges that accommodate varied skill levels and learning paces. The application extends the principles of unplugged activities by using digital features to provide instant interactivity, feedback, and customization. It integrates educational content within a game structure that emphasizes aesthetics, narrative, and reward to re-shape perceptions of CS.

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Three diverse guide characters accompany users throughout the app, namely Alex, a data scientist; Pixie, a digital artist; and Iris, a graphics programmer. Binary Spectrum supports three languages (English, German, and Brazilian Portuguese) and includes features as an achievement system to enhance motivation, information buttons providing conceptual support, and multisensory elements like animations and sound effects. The bright and playful visual design aims to lower the barrier to entry and enhance user engagement.

2.1 Mini-Games

Each mini-game teaches one computing concept through creative activities inside challenges with increasing difficulty.

BitPearls This mini-game teaches binary numbers and decimal-to-binary conversion through interactive manipulation of binary digits. Learners create digital "binary armbands" by converting their birthdays into binary patterns.

PixelPrism This mini-game teaches digital image representation. Learners interact with black-and-white pixel grids to explore resolution, data size, and compression principles through creative pixel painting exercises.

ColorBloom This mini-game teaches RGB color mixing, hexadecimal color codes, and opacity concepts. Learners experiment with interactive color tools and matching challenges (like in figure 2) to understand how digital colors form and change.

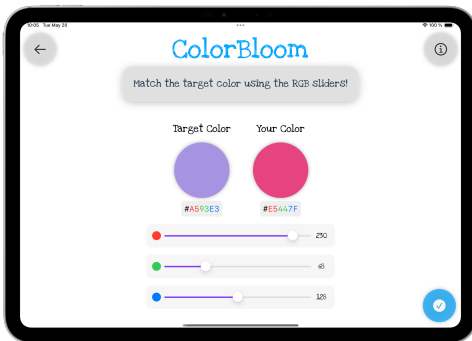


Figure 2: One of the challenges of ColorBloom.

2.2 Implementation and Current Status

Binary Spectrum runs as a native iPad application developed with Swift and SwiftUI. All required resources are bundled within the app, allowing it to run offline with minimal setup.

Each mini-game targets short learning units and takes 15-20 minutes to complete. The modular design enables educators to adapt the app to various educational settings. In classrooms, teachers integrate individual games into 45-60 minute lessons or combine multiple games for an extended unit. Coding clubs use standalone activities to focus on targeted concepts. The self-contained games enable exploration outside formal settings for independent learning.

The implementation of Binary Spectrum aligns technical functionality with design goals grounded in gender inclusion research.

The app integrates diverse characters, narrative framing, and playful aesthetics to create a space where girls feel represented and invited to participate. Each mini-game turns abstract CS concepts into goal-driven challenges that aim to spark curiosity and sustain interest. These design choices complement the modular architecture, which supports flexible use across different learning environments.

3 CONCLUSION

Binary Spectrum exists as a complete iPad application. It contains three mini-games, challenges with increasing difficulty, an achievement system, and multilingual support. Binary Spectrum addresses the need for inclusive, adaptive CS education tools that engage learners of all genders.

Binary Spectrum creates an alternative approach to early CS education by delivering inclusive, gamified learning experiences that teach core representational systems like binary numbers, pixel grids, and color encoding. This approach increases the inclusivity of computing education by providing learning experiences that engage and match each learner's developmental level. This initiative identifies and refines new pathways for children to engage with foundational CS concepts, supporting a more diverse and representative future in technology.

Future development will focus on comprehensive classroom evaluation with diverse learner populations to measure learning outcomes, engagement, and usability. Content expansion will create new mini-games covering algorithms, data structures, and logical operations. Advanced accessibility features including voice-over and colorblind-friendly design will be added to make the application more inclusive.

REFERENCES

- [1] Christian P. Brackmann, Marcos Román-González, Gregorio Robles, Jesús Moreno-León, Ana Casali, and Dante Barone. 2017. Development of Computational Thinking Skills through Unplugged Activities in Primary School. In *Proceedings of the 12th Workshop on Primary and Secondary Computing Education*. 65–72.
- [2] Tracy Fullerton, Janine Fron, Celia Pearce, and Jacki Morie. 2008. Getting girls into the game: Toward a virtuous cycle. *Beyond Barbie and Mortal Kombat: New perspectives on gender and gaming* (2008), 161–176.
- [3] Daniaal Hooshyar, Liina Malva, Yeongwook Yang, Margus Pedaste, Minhong Wang, and Heuseok Lim. 2021. An adaptive educational computer game: Effects on students' knowledge and learning attitude in computational thinking. *Computers in Human Behavior* 114 (2021).
- [4] Charles Huff and Joel Cooper. 1987. Sex Bias in Educational Software: The Effect of Designers' Stereotypes on the Software They Design. *Journal of Applied Social Psychology* 17, 6 (1987), 519–532.
- [5] Caroline Criado Perez. 2019. *Invisible Women: Data Bias in a World Designed for Men*. Abrams.
- [6] Yucnary-Daitiana Torres-Torres, Marcos Román-González, and Juan-Carlos Pérez-González. 2019. Implementation of Unplugged Teaching Activities to Foster Computational Thinking Skills in Primary School from a Gender Perspective. In *Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality*. 209–215.
- [7] Yune Tran. 2019. Computational Thinking Equity in Elementary Classrooms: What Third-Grade Students Know and Can Do. *Journal of Educational Computing Research* 57 (2019), 3–31.
- [8] Sarita Yardi and Amy Bruckman. 2007. What is computing?: bridging the gap between teenagers' perceptions and graduate students' experiences. In *Proceedings of the Third International Workshop on Computing Education Research*. 39–50.