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Teaching the principles of artificial intelligence to Generation Z

The SMaILE-App mobile game application

Maria Giulia Ballatore 0000-0002-6216-8939,

Sara Bernardini 0000-0002-1021-6900,

Giacomo Como 0000-0002-2176-9586,

Luca Damonte 0000-0002-9314-0883,

Santiago Franco 0000-0001-7430-5278,

Alexandra Neascu 0009-0003-7798-8598, and

Martina Vanelli 0000-0001-5578-404X

Artificial Intelligence (AI) has increasingly become a significant component of our daily routines. Therefore, it is crucial for society to familiarise young people with AI early on in their lives. We present our educational experience with the SMaILE (Simple Methods for Artificial Intelligence Learning and Education) research project. We focus on the design and development activities of SMaILE-App, a mobile game application, to teach teenagers the fundamental principles of AI. Following a constructionist pedagogical approach, SMaILE-App engages its users to learn and understand AI through suitably designed games. SMaILE-App primarily targets 12- to 18-year-old students but can also appeal to a broader audience of non-experts interested in AI technologies. Formalising the fun activities within SMaILE-App aims to facilitate a deep understanding of AI in its users. We describe SMaILE-App's city-building game following Schell's elemental tetrad: story, game mechanics, aesthetics, and technology.

Introduction

The digital revolution and widespread integration of Artificial Intelligence (AI) technologies into various aspects of society present both opportunities and challenges (Admiraal et al., 2014; Dewey, 1916). To ensure the successful utilisation of AI for the benefit of humanity, it is crucial that individuals be equipped with strong digital competencies, with AI concepts playing a central role in this landscape. Investing in education to foster advanced digital, cognitive, and sociotechnical skills is essential for enabling people to engage effectively with technology, enhance employability, and adapt to evolving technological advancements. However, in several countries, including Italy and the United Kingdom, digital competencies, especially those related to AI, are inadequately integrated into primary and secondary school curricula. Addressing this issue is of the utmost importance, and the SMaILE (Simple Methods for Artificial Intelligence Learning and Education) research project strives to tackle this challenge (SMaILE, 2021). SMaILE seeks to make a substantial impact on the educational journeys of Generation-Z children, particularly those aged 12–18, by employing innovative teaching methodologies, including gamification techniques.

One of the key outcomes of the project is SMaILE-App, a mobile game application designed to impart the fundamental principles of AI. This chapter focuses on elucidating SMaILE-App's narrative and game design. It outlines the app's objectives and delves into its game design, which follows Schell's elemental tetrad approach (Schell, 2019, p. 610). Additionally, the chapter discusses testing activities and feedback received and concludes with reflections on the project's significance in addressing the imperative need to incorporate AI education into the school curriculum. SMaILE-App serves as a valuable tool in this endeavour to empower young learners with essential digital skills and AI awareness.

SMaILE-App's game design

SMaILE-App targets young learners from lower and upper secondary schools. Their creativity and sense of agency are stimulated by entertaining, hands-on learning activities concerning AI. Users can develop simple but meaningful activities within SMaILE-App by playing. Simultaneously, since AI is founded on mathematical principles, spatial aptitude, and computational thinking, we anticipate that users will also benefit from it.

Developing such abilities in children is likely to have a significant impact on both their future growth and the community as a whole (Williams et al., 2019). The idea behind SMaILE-App is based on the constructionist pedagogical approach, as introduced by Dewey and Piaget in their theory of cognitive development (Resnick, 2017; Vonèche, 1983). The game commences with a set of real-world issues that could be addressed by AI, and players gradually acquire the necessary foundations to devise and implement solutions for such problems. This approach makes learning more exciting while also showing that AI is a multidisciplinary field that requires many skills. Exactly as stated by Dewey (1916, pag. 190): "Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results".

SMaILE-App is available for Android and iOS devices and offers a unique one-player simulation experience in the realm of city-building games. Its overarching goal is to enable players to create and manage a smart city, with a strong emphasis on sustainability. The game starts with a 2D perspective and gradually transitions into a dynamic 3D environment. The application features diverse game modes, ranging from intuitive street view-style navigation to the more traditional touch-and-drag controls commonly found in mobile gaming. Designed primarily for first and second-grade secondary school students aged 12–18, SMaILE-App is also accessible to a broader demographic. It has been designed considering the extensive literature on how gender preferences can influence gaming experiences (Admiraal et al., 2014; Robertson, 2012). Historically, male gamers have shown a penchant for elements such as control, competition, destruction, spatial puzzles, and trial-and-error mechanics, while female gamers have demonstrated a greater affinity for emotionally engaging narratives, real-world contexts, dialogue, verbal puzzles, and experiential learning. To bridge this gap and cater to both genders, SMaILE-App strategically integrates features that harmoniously blend these preferences while ensuring an inclusive and user-friendly experience. This section will delve into the game's narrative, mechanics, aesthetics, and technology, following Schell's elemental tetrad (Schell, 2019).

Players start out in the role of the mayor of a futuristic city. The primary objective is to construct a thriving metropolis from the ground up, starting with a sustainable master plan to enhance liveability. Once the city's regulations are established, players are tasked with building, managing, and maintaining various services and activities. To imbue players with a fundamental understanding of AI concepts, they must engage in several games, called minigames, as part of their mayoral duties. Successfully completing different levels not only increases the city's population but also improves its overall liveability score, unlocking new activities and services for expansion. The players are accompanied by a stylised robot assistant, akin to SMaILE's project logo, who offers guidance on the AI fundamentals that underlie various in-game activities.

SMaILE-App presents a dynamic and unique hybrid game environment. It consists primarily of three canvases: the 3D aerial cityscape (see Figure 19.1, left), the 3D exploratory immersive cityscape (see Figure 19.1, right), and the 2D minigame-specific frameworks. This environment enables players to explore individual tiles, discover their specific characteristics, and engage in associated minigames, all aligned with tile functions. The game's graphics provide a sophisticated 3D first-person perspective for city navigation and exploration. Sound effects serve dual purposes, enhancing entertainment during single-player games and facilitating interaction when the robot assistant who offers guidance. The user interface provides essential information, such as population and sustainability scores, in a 3D view following city construction. Players can access detailed information on each tile by double-tapping the desired area, with pop-up instructions tailored to the tile type (Schell, 2019).

Figure 19.1 On the left, the 3D aerial cityscape. On the right, the 3D exploration.

Every minigame played enables players to accumulate population and sustainability points, both of which independently affect the city's overall liveability. Optimal solutions may differ, as increasing the population spawns new tiles for city expansion while achieving higher sustainability levels unlocks additional activities and services along with more challenging maintenance tasks. From a pedagogical perspective, each tile correlates with specific learning outcomes, with each game rooted in a fundamental AI concept. Table 19.1 provides a concise overview of these learning outcomes and their associated game mechanisms.

Table 19.1 Table of learning outcomes.

Sust. level	Tile type	Learning outcomes	Game mechanism
0	City building	Constraints satisfaction	Create master plan to address the problem
0	City Hall	Theoretical contents	Analyse the plays and read about the theoretical concepts of each game
1	Hospital	Heuristic search	Move the patients to the right spot
1	Park	Decision tree and Minimax algorithm	Decide what are the best solutions to repurpose empty land
1	Recycling centre	Combinatorial game theory	Organise waste collection
1	Planting	Adversarial games	Plant seeds in the park
2	Supermarket	Neural networks and image recognition	Organise products on the shelves
2	Station	AlphaZero	Interact with a trained avatar
3	School	Reinforcement learning	Teach a school bus how to properly collect kids and reach the school
3	Cinema	Natural language processing	Create the plot of a movie

SMaILE-App is optimised to run on modern mobile devices, including both phones and tablets. Its core components include three distinct canvases: an initial 2D grid, the 3D city, and the minigame framework. Beyond typical mobile gaming features, SMaILE-App seamlessly integrates AI concepts implemented in Python code, thereby enhancing the city's intelligent and technological aspects. Valuable player data is recorded for both gameplay analysis and pedagogical purposes.

Description of minigames

SMaILE-App employs a three-stage progression system in which players must attain a predefined score threshold in associated minigames to advance. Each minigame has a score cap to promote balance and prevent reliance on a single game. Unlocking new minigames provides access to instructional videos on AI theory and game-specific strategies, enhancing the learning experience. Below, we provide a concise overview of the mechanics, aesthetics, and educational content of each minigame.

The CityBuilding minigame operates on hexagonal grids ranging from 6 × 6 to 10 × 10 in size that offer the intriguing challenge of formulating a master plan for the city. Players must arrange a predetermined number of hexagonal tiles representing various attractions and services in different configurations to achieve the highest possible liveability score. At the outset, players are provided with three types of tiles: 15 houses, 5 parks, and 3 hospitals. With an empty grid before them, players use finger gestures to position the available tiles, intricately interlocking them. Each tile configuration is meticulously scored based on its arrangement in relation to other blocks, quantifying the degree of liveability it offers to the city. The scoring system rewards the proximity of houses to service tiles. Specifically, the score is a weighted sum of the number of houses attached to or within one tile distance from the service tiles.

In the game's initial stages, players are limited to three types of tiles: houses, hospitals, and parks. The scoring system awards 10 points for houses attached to a park and 3 points if they are one tile away. Houses attached to a hospital yield 15 points, and those that are one tile away give 5 points.

Once players have meticulously arranged the tiles to create their preferred configuration, the next step is crucial: they must formalise the overarching guidelines into a comprehensive set of rules. This serves as the blueprint for SMaILE-App's built-in Constraint Satisfaction Programming (CSP) solver. The CSP solver automates the city planning process, ensuring adherence to the player's vision and the specified liveability criteria. The pedagogical goal here is to help players grasp CSP models by allowing them to modify rules. Upon formulating the master plan, the city is generated in accordance with its requirements. If the player is satisfied with the result, they can proceed with implementing and maintaining the city. This iterative process encourages players to balance aesthetics, functionality, and sustainability while also gaining a deeper understanding of constraint satisfaction programming. An instructional video on CSP theory covers variables, domains, and constraints, using the classic map-colouring example to illustrate these concepts.

The Hospital minigame is an adaptation of the classic Sokoban (Junghanns and Schaeffer, 1997; Studio, 2023) puzzle game, employing a hexagonal grid for enhanced gameplay. This choice of a hexagonal grid serves a dual purpose: it aligns with the design consistency of the Citybuilding game and provides players with expanded movement options to navigate obstacles effectively. The game board can vary in size up to 9 × 9 hexagons and features a nurse as the player's agent, specific goal cells, and beds corresponding to these goals. Players can perform two actions in the game: 'move' to reach empty hexagons and 'push' to move beds by clicking on them. There are twelve progressively challenging levels, each one introducing more beds and increased difficulty. To earn bonus points, players must solve each level in the fewest moves possible. The game displays the minimum moves required for successful completion, ensuring players master each level before progressing.

The educational aim of the Hospital minigame is to illustrate how heuristics can simplify complex problems, though they may not always provide the most effective solutions. To facilitate learning, the game incorporates an AI "hint" system allowing players to choose a subset of goal positions based on distance heuristics. While the hint system suggests a way to achieve selected objectives, it is emphasised that executing the suggested actions will not necessarily result in a satisfactory or valid strategy. This minigame adds a valuable dimension to SMaILE-App's educational content, offering students the opportunity to engage with AI concepts in a practical and thought-provoking manner. The instructional video for the game warns players that, while the heuristic hints suggest a way of accomplishing the selected group of objectives, there is no guarantee that carrying out the suggested actions will yield a satisfactory or even valid strategy.

The Park section of SMaILE-App comprises three minigames: park selection, planting, and recycling, each designed to teach players key strategies and techniques relevant to AI, decision theory, and combinatorial game theory (Karlin and Peres, 2017).

In the park-selection minigame, players must strike a balance between optimizing citizen satisfaction and minimizing environmental impact while constructing a park. They rely on citizen feedback and environmental impact data to make informed decisions, with higher interest scores leading to greater environmental impact. The game employs a decision tree, categorised into options such as gardens or playgrounds, and utilises the Minimax decision algorithm (Russell and Norvig, 2021). This algorithm, familiar to users from adversarial games, aims to optimise choices while considering the best possible countermoves, introducing players to decision trees and adversarial search.

Planting is an enhanced version of Tic-Tac-Toe on an 11 × 11 grid, where the goal is to connect four tiles. Players can face off against easy, medium, or hard opponents trained using an adapted AlphaZero algorithm (Silver et al., 2018). An educational video accompanies this game, highlighting the limitations of the Minimax algorithm in large search spaces and the concept of progressively improving a virtual player through iterative training.

Recycling introduces players to the optimal strategy of the Nim game (Berlekamp, Conway, and Guy, 2001) through a waste collection challenge. Players take turns removing waste to claim the last item, with adjustable AI opponent difficulty levels. The educational video covers binary arithmetic operations, equipping players with the skills to beat expert-level AI opponents.

These minigames offer engaging ways to introduce players to various AI-related concepts, decision-making strategies, and game theory principles, enhancing their understanding of these topics in a fun and interactive manner.

The Supermarket game teaches image classification using Convolutional Neural Networks (CNNs). Users first train an AI to identify vegan and non-vegan items using 30 cartoonish images. Subsequently, users tune the model’s parameters by adjusting the quantity of colours, image resolution, and neural network layers. The neural network is then optimised and ready for use. While data augmentation techniques such as rotation and zooming were tested, they did not significantly influence the model’s accuracy. In the educational video, players are introduced to fundamental concepts in the field of Artificial Neural Networks (ANNs). The video explains essential elements such as image layers, input methods, filter application, and labelling techniques, as well as the distinction between training and test data sets. Furthermore, the practical video provides players with guidance on effectively labelling images for the game, while also addressing the trade-offs between image resolution and computational efficiency.

In the Station game, players gain the ability to fine-tune the AlphaZero algorithm (Silver et al., 2018), a key component of the planting minigame. They can adjust three crucial parameters: rollouts, cuts, and the winning threshold, while also having access to their virtual adversaries' parameter values. An educational video provides a historical perspective on AlphaZero, tracing its evolution from Minimax to Deep Blue-like algorithms in the 1990s. It explains the role of CNNs as heuristics for evaluating game states and introduces Monte-Carlo search, building on the heuristic search concept from the Hospital game.

The video delves into Monte-Carlo as a parameterised stochastic search algorithm, elucidating the function of rollouts. It unveils AlphaZero's core idea, utilizing CNNs to refine known strategies and employing Monte-Carlo search to efficiently explore new moves. The game-specific video guides players through the trade-offs associated with parameter values, connecting these choices to the exploration vs. exploitation concept. Overall, the Station minigame equips players with the knowledge and tools to customise the AlphaZero algorithm and prepares them for strategic gameplay in the Planting minigame.

The School game introduces players to Reinforcement Learning (RL) principles through a school bus scenario. It offers eight progressively more challenging levels, each with unique training and testing maps. An autonomous agent navigates a grid with five cell types: road, sidewalk, bus stop, school, and visited. The agent can move in four directions but faces restrictions on sidewalks and map boundaries. Q-learning (Watkins and Dayan, 1992) is employed, with rewards for efficient routing to bus stops and schools and penalties for inefficiency. The educational video focuses on exploration and exploitation concepts in RL, emphasizing the agent's gradual shift towards favouring optimal actions.

In the game, players select a level, examine the test map, and choose one of three training maps to develop an optimal strategy. They can place bus stops on the training map to simulate potential agent states from the test environment. The Q-learning algorithm runs in the background, generating routes that reflect the agent's learning. Players assess the agent's performance score and routes on the test map, allowing them to identify inefficiencies and refine their strategy accordingly. This game provides hands-on experience with RL principles in a practical school bus context.

The Cinema module serves as a demonstration of AI in an advisory role. Users input a script focused on environmental awareness, and the AI performs two key tasks: it generates a word cloud from the script and matches it against a library of hundreds of educational films created by K-12 students. The system then ranks the five most similar existing movies, which users can then watch using the app’s built-in video player. The accompanying educational video delves into AI recommendation systems and introduces the concept of WordClouds.

SMaILE-App in the field

We conducted an initial focus group session with sixteen children aged 10–13 in June 2021 to assess various aspects of the game, including its mechanics, activity difficulty, and playability. The group was evenly split by gender. During this session, students were introduced to the app and played the sustainability level 0 in a paper format. This tactile approach allowed them to focus on the game’s story and mechanics rather than its aesthetic components.

Following gameplay, we engaged the participants in a discussion about the game’s design. The feedback indicated strong interest in the storyline and an engaging gameplay experience. The process of city-building was described as “challenging, difficult, and demanding”, yet “fun, like a puzzle”.

Participants were tasked with manually calculating their scores, a task that was perceived as time-consuming and demanding. Nevertheless, some found value in this exercise as it provided insights into how the scoring system operates. This feedback underscores the importance of addressing score calculation in the app’s aesthetics. While the mobile version automates this process, it is deemed necessary that the components of the score be displayed, not only the final total.

Furthermore, defining constraints was identified as a complex activity, with some students expressing difficulty in grasping how constraints function. The participants appreciated witnessing the city being autonomously constructed and expressed curiosity about viewing constraints defined by neighbouring cities in the app.

In the subsequent evaluation phases, we organised two gender-balanced focus groups in schools, each consisting of 20 students aged 11–12. The first group tested three games, while the second group evaluated the remaining ones. Based on their feedback, we made targeted adjustments to game tutorials and narratives to enhance clarity and simplicity.

Additionally, we conducted app testing with two groups of 40 students aged 10–18 at Salone del Libro di Torino and Giffoni Film Festival.

In the third phase, we conducted a Randomised Control Trial (RCT) involving approximately 900 middle school students. A comprehensive analysis of the RCT results will be carried out as part of future work. Here, we focus on the GUESS-13 questionnaire (Phan, Keebler, and Chaparro, 2016) results from the 450 students who had access to the app, assessing user experience and satisfaction levels.

The GUESS-13 questionnaire, comprising thirteen targeted questions, enabled us to evaluate various aspects of gameplay, including playability, user-friendliness, learning ease, visual appeal, and player engagement. By combining these results with the collected gender data, we gained valuable insights into our gender-specific objective: to design an informal learning environment that stimulates greater interest in AI among girls.

More precisely, our findings revealed noteworthy distinctions between committed players and uncommitted players, where the former engaged with the app for an average duration of more than an hour. This distinction was particularly significant in questions related to user satisfaction (I1 and I7), highlighting the positive impact of prolonged engagement.

When comparing male and female responses among frequent players, a distinct gender preference emerged. Female players exhibited a stronger affinity for the app’s visuals, engagement factors, design, and balance (I4, I5, I8, I9), while both genders expressed a shared desire for enhanced graphics quality. This underscores the app’s success in engaging female students and aligns with our gender-inclusive design goals.

Overall, the GUESS-13 analysis affirmed SMaILE-App’s ability to effectively engage players aged 10–18, especially females, by integrating AI concepts into a captivating educational experience. While acknowledging areas for improvement, particularly in graphics quality, the analysis underscores the app’s potential to positively impact educational settings. The positive reception from committed players and significance of gender preferences present promising avenues for the app’s future development and its contribution to AI education.

To further advance our commitment to the AI educational community, we have made SMaILE-App and its code publicly available, thus fostering the dissemination of AI-centric activities and games for K-12 students.

In the multifaceted world of educational game design, feedback stands out as an invaluable compass helping designers chart the course toward refinement and innovation. As we delve into the feedback provided by our users at the end of GUESS-13, one resounding theme emerges: the potential for growth and enhancement. As one discerning student aptly observes, “the game offers a captivating experience, but there remains room for improvement”. This candid remark encapsulates the essence of feedback – an opportunity for progress. Further insights from our user base reinforce this notion. Suggestions such as “expanding the virtual environment with additional buildings” and “introducing greater variety to reduce repetition” offer clear directives for evolution. Moreover, astute remarks such as “consider refining the game’s graphics for a more immersive experience” and “simplifying the gameplay for broader accessibility” are pearls of wisdom that illuminate the path to refinement. It is essential to recognise that this educational game, like any scholarly pursuit, is a continuous work in progress. As eloquently put by one user, “the game is a canvas awaiting its masterpiece”. We find in these words the inspiration to persistently iterate, building on the feedback-fuelled foundation and shaping SMaILE-App into an ever-evolving platform for education and engagement.

It becomes evident that SMaILE-App has struck a resonant chord with its audience. The app’s capacity to simultaneously engage and educate has garnered praise, with students commending its “interactive and immersive learning experiences”. One recurring sentiment is appreciation for the real-world applications of engineering concepts, which students found both educational and enjoyable. Furthermore, the app’s user-friendly interface and intuitive navigation received accolades, as it simplified the learning process and allowed students to “focus on the content rather than struggling with the technology”. In essence, it is heartening to witness how SMaILE-App has successfully harnessed the power of gamification to captivate students’ interest while imparting valuable knowledge, thereby fostering a learning environment in which enjoyment and education intertwine.

Conclusion

SMaILE-App is a comprehensive educational app that immerses users in the diverse world of AI through experiential learning. This “learning by doing” approach effectively encapsulates various facets of AI. User feedback has been overwhelmingly positive, highlighting the app’s success in achieving its educational goals. Importantly, the app’s gender-inclusive design has yielded statistically significant positive responses from female users, thus promoting gender equity in AI education.

Additionally, the impact of SMaILE-App extends beyond student engagement to also serve as a valuable resource for teacher training. By integrating AI content into classroom activities, it contributes to a more tech-savvy generation of educators. Moving forward, the focus will be on the final analysis of the RCT to assess the app’s impact on AI knowledge and related skills. Notably, SMaILE-App has received recognition in the field of engineering education. Its selection as a finalist for the GEE! Awards for Informal Learning and its having won the GEE! People’s Choice Award underscores its educational significance and the widespread support it enjoys within the educational community. These accolades affirm its role as a valuable tool for excellence in engineering education.

In conclusion, SMaILE-App stands as a testament to the potential of experiential learning and inclusive design, paving the way for a brighter future in AI education in which learners of all backgrounds can engage effectively in the world of AI.

Author contribution statement

All of the authors collectively engaged in this chapter's conceptualisation and methodology phases. MGB, LD, SF, AN, and MV were responsible for the validation, investigation, and resource allocation. Additionally, they were the primary contributors to the original draft. SB and GC supervised the writing process and they reviewed and edited the manuscript. LD, SF, and AN contributed to the software development. Furthermore, GC was responsible for the project's administration and funding management. All of the authors discussed the text and revised the final manuscript.

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