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Prototypes of Digital Simulators and Board Games for Cervical Cancer Prevention: Insights from Cytology Professionals

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Abstract: *Introduction:* This study explores the importance of robust pathology education for health science students, emphasizing the challenges of curriculum standardization, inconsistencies, and limited access to practical experiences. In Brazil's public health landscape, cervical cancer remains a significant challenge, underscoring the need for preventive measures such as Human Papillomavirus (HPV) detection testing. *Objective:* To address gaps in the educational field, tools like digital simulators and board games offer promising potential for fostering practical and dynamic learning experiences. *Methods:* A simulator was developed on the Unity platform, integrating features of a physical board game to enhance interactivity. In the first phase of this study, perceptions of gynaecological cytology professionals were evaluated regarding the use of a digital simulator as a complementary tool for skill development. Subsequently, a small group of students tested the simulator and assessed it using the categories of the Pleasure Framework to capture affective responses. *Results:* Among 74 professionals surveyed, 50% strongly agreed that using a digital simulator would improve their training in gynaecological cytology, and 36% believed it would positively contribute to clinical practice. Nursing students reported positive emotional engagement during the test sessions, particularly in the categories of simulation, exploration, and camaraderie. *Conclusion:* Assessing this educational technology is crucial for determining its effectiveness in improving the teaching and learning process and its potential integration into academic health training.

Keywords: cervical cancer, digital simulator, board game, health professional education

1 Introduction

The education of healthcare professionals is fundamental to ensuring an effective and high-quality health system. Within this framework, providing comprehensive and up-to-date training in pathology is essential, as this discipline supports the diagnosis and management of numerous medical conditions, including cervical cancer. As noted by Mehanna and Garbelini [2021], a deep and thorough understanding of pathology is critical for achieving clinical excellence.

Cervical cancer represents a significant public health issue in Brazil, ranking as the third most common type of cancer among women, according to the National Cancer Institute [INCA, 2023]. Each year, around 17,000 new cases are estimated in the country, underscoring the scale of the challenge and the pressing need for preventive and early detection policies. In response to this scenario, it is crucial to design effective measures aimed at lowering both incidence and mortality rates, while also improving access to information, diagnostic services, and adequate treatment. The Brazilian Ministry of Health recently included the Human Papillomavirus (HPV) detection test in its public health guidelines. HPV is the main etiological agent of cervical cancer, being responsible for approximately 99% of cases, which makes it a strategic focus for prevention. This initiative aims to promote early diagnosis and reinforce control measures to reduce cervical cancer incidence. Furthermore, according to the National Commission for the Incorporation of Technologies in the Unified Health System [CONITEC, 2024], the adoption of the HPV test represents a significant advancement in public health, enabling timely intervention before the disease progresses.

However, despite these efforts, there is still a notable shortage of didactic materials to educate both healthcare professionals and the general population about HPV and its implications, revealing an educational gap that limits the effectiveness of preventive strategies. The modernization of pathology teaching resources, in alignment with national curriculum guidelines, is essential to ensuring high-quality education for future healthcare professionals. The absence of curricular standardization, coupled with insufficient practical training, compromises learning and hinders the adequate preparation of students to meet the demands of the healthcare system [Germano da Silva *et al.*, 2024b; Soares and Athanazio, 2016]. Additionally, the lack of validated instructional tools in the field of cytopathology constitutes a critical

gap. Addressing this issue could strengthen educational efforts focused on raising awareness and preventing cervical cancer [Hipólito *et al*., 2024; de Oliveira *et al*., 2016].

In this scenario, interactive educational strategies such as digital simulators and board games have emerged as promising alternatives. These resources provide a hands-on and engaging learning experience that supports skill development and may play an important role in addressing public health challenges [Krishnamurthy *et al*., 2022; Nayar and Wilbur, 2018; Spiegel *et al*., 2008; Leone and Pinto, 2023]. The present study is an extended and revised version of the article by [Germano da Silva *et al*., 2024a], originally presented at the Brazilian Symposium on Games and Digital Entertainment (SBGames).

2 Related Work – Inspiring studies for prototype development

Martinovski *et al*. [2023] developed a low-cost simulator for health education. The developed simulator was a low-fidelity, low-cost tool designed to educate about the Papanicolaou test and the anatomy of the cervix. They used a cardboard box with an opening that simulates the vaginal canal, covered with pink Ethylene Vinyl Acetate (EVA) to represent the external genital organs. EVA is a soft, lightweight, flexible foam that is commonly used in crafts, toys, and prototypes because of its ease of cutting, glueing, and handling. Inside, there is a Light-Emitting Diode (LED) to illuminate the cervix. The simulator allowed visualization of the main components of the female genital organ, as well as representation of different types of cervix with interchangeable slides. This approach aims to provide a realistic representation of the procedure, facilitating patient understanding and increasing patient adherence to the test. The feedback from nurses and patients was positive, emphasizing the effectiveness of the simulator in promoting health education and addressing concerns, thus enhancing the understanding of the procedure and its possible results. The authors perceived a gap in the literature regarding the lack of studies on simulator technologies aimed at sexual reproductive health education.

Hipólito *et al*. [2024] developed a serious game (SG) for teaching the technique of material collection for cervical cytopathology exams, aimed at nursing students from the University of Campinas (*Universidade Estadual de Campinas* - UNICAMP) enrolled in the women's health care course. Twenty-four students agreed to participate in the Serious Game and completed an evaluation form, in addition to the specialists who validated the SG. The results showed that 100% of the students agreed with the integration of technologies into the curriculum content and considered the SG enjoyable and educational. Additionally, 83% of the students reported feeling motivated during the game. It was concluded that the SG met expectations for skill development, offering clear, relevant, and comprehensive content, in addition to excellent usability and utility for learning the technique. To encourage clinical reasoning, it was suggested to incorporate debriefing questions, either instructor-led or the student in a self-instructional approach. The use of the SG and other simulation methods can significantly enhance students' preparation for women's healthcare, including the correct execution of the techniques necessary to ensure the quality of sample collection and accurate test result interpretation.

The game "Working with the Cellular Machine" is an innovative educational tool developed to make the learning of molecular biology in high school more engaging and effective. This game goes beyond simply presenting theoretical concepts by providing a practical and interactive experience, where students are actively challenged to solve problems related to molecular biology. Players assume the role of human immune system agents, facing a second bacterial invasion, and must assist the body in producing antibodies to combat the infection. Throughout the game, they encounter questions that cover topics such as replication, transcription, and translation of deoxyribonucleic acids (DNA), represented visually and tangibly on the game board. Each player is responsible for answering questions based on their molecular biology knowledge, filling in the board, and advancing in the game. The game's competitive and collaborative dynamics foster student engagement as they work together to achieve the ultimate goal of producing the antibodies necessary to defeat bacterial infection. In addition, the game offers an interdisciplinary approach linking concepts of molecular biology with other fields, such as immunology and cellular biology. This provides players with a more holistic and contextualized understanding of the biological processes involved in the immune response of the body. Evaluations from teachers and students highlighted the effectiveness of the game as a teaching tool, noting a significant increase in understanding molecular biology topics and greater student involvement in the learning process [Cardoso *et al*., 2008].

"Inside the Cell" is an investigative board game that explores enigmas related to Cellular and Molecular Biology. Players, organized into groups of up to 12 students, analyze clues to solve the puzzles, developing skills such as reasoning, interpretation, and synthesis. The game targets high school and college students, and it can be played competitively or cooperatively, with the teacher acting as a coordinator and guide. Its educational objectives include promoting active student participation, encouraging teamwork, interpreting scientific data, and simulating the scientific research process. With five different puzzles, the game covers topics such as the origin of mitochondria, the structure of the plasma membrane, and forensic molecular biology. Evaluations indicate that "Inside the Cell" is well-received by students, promoting learning in a dynamic and fun way, while also developing essential skills for understanding Cellular and Molecular Biology [Spiegel *et al*., 2008].

The "Lockdown: All Against the Virus" is a modern cooperative board game that simulates family life during a lockdown period imposed by a highly contagious respiratory virus pandemic. Players represent families and must manage daily activities while ensuring the continued functionality of community services and prioritizing education. The game consists of six rounds, each with seven phases, where players collect resources, manage infections, and direct individuals to places like schools and pharmacies. Exploring socioscientific issues promotes collective strategies, empathy, and critical discussions. Designed for teaching science and health, the game can be used for both educational activ-

ities and teacher training, covering topics such as physical distancing, vaccination, and virus prevention. This game, still in prototype, offers the opportunity to explore pandemic-related issues in a playful and educational way [Leone and Pinto, 2023].

Lopes *et al*. [2024] proposed a structured gamification strategy for remote education, highlighting the use of game elements to foster student engagement and autonomy. Although not specific to healthcare education, their approach illustrates how pedagogical frameworks can inform the design of interactive educational tools. Their work also contributes to diversifying the academic landscape, as it is led by Brazilian women researchers publishing in national venues.

Brandão and Baranauskas [2025] proposed a conceptual framework for socienactive play scenarios, understood as experiences that integrate the physical, digital, and social dimensions in a coordinated and simultaneous manner to enrich learning. The study was conducted with students from the Federal University of ABC (UFABC), Brazil, within the scope of the ParaJecripe Brandão *et al*. [2016]; Domingos *et al*. [2017]; Silva *et al*. [2023] outreach community project, and involved the participatory co-design of an inclusive racing game in which sighted teammates guide blind players. This dynamic highlighted the potential of ludic collaboration to foster social inclusion. The proposal combined collaborative interactions, multisensory feedback, and physical devices supported by digital technologies to promote accessibility and participant engagement. The results indicated increased student involvement and reinforced the pedagogical potential of socienactive approaches in inclusive and diverse educational settings.

The reviewed studies demonstrate the growing adoption of ludification strategies and hybrid approaches to promote engagement and knowledge retention in educational contexts, including in the field of health sciences. In particular, initiatives led by Brazilian women researchers highlight the national potential for innovation in this area. These works directly inspired the design and iterative improvement of the simulator developed in this study, especially in terms of interactivity, physical-digital integration, and alignment with national curriculum guidelines. Building on these contributions, we adopted a hybrid approach that combines physical and digital elements and may promote contextualized, collaborative, and engaging learning experiences.

3 Ethical Considerations

This project was approved by the Unifesp Research Ethics Committee –- CAAE 75286923.0.0000.5505. All students who participated in the simulation signed the Informed Consent Form (ICF), ensuring voluntary participation in compliance with ethical standards. The simulator was designed with secure protocols to prevent data breaches, and the collection of personal information was limited to the minimum necessary for conducting the research. Video recordings of the sessions were stored in a secure, access-restricted environment and used solely for research analysis purposes. All audiovisual materials will remain confidential and will not be shared publicly or used for identification. Data will only be disclosed in anonymized form, ensuring that any possibility of direct or indirect identification of participants is eliminated, under Article 7, item IV, of Brazilian Law No. 13.709/2018 (General Data Protection Law – LGPD). In the future, both the board game and the simulator will be made freely available in open-access format, with DOI registration, allowing educators, researchers, and healthcare professionals to freely access and apply these tools in academic and training settings.

3.1 Participatory Design Planning

The development of the simulator followed a design-based research approach, structured in stages, beginning with the identification of educational needs in the teaching of pathology, particularly cytopathology. Before creating the digital prototype, an opinion poll was conducted with cytology professionals to identify key gaps and define the educational goals of the tool. A co-creation process was adopted, involving two main groups of co-designers: (1) the technical development team, composed of computer science professionals, and (2) health specialists. During the co-design sessions, initial physical-digital prototypes were created using storyboards that included both the board game and the simulator interface, following the framework from [Rutes *et al*., 2015]. Feedback from health professionals guided iterative improvements in visual and content design, aiming to enhance clarity, usability, and the pedagogical effectiveness of the tool, in line with user-centered design principles.

4 Results and discussion

To fill the gap created by the lack of uniformity in the syllabus and the limitation of practical classes, which hinder the qualified training of students, an opinion poll was carried out with professionals in the field of cytology on the concept of the simulator. Next, the simulator prototype was developed and submitted to preliminary tests by some students before the Beta version was released. At the same time, the board game prototype was created, introducing an initial version of the hybrid approach combining physical and digital components. The following topics will present the results and discussion of each of these stages.

4.1 Perception of gynaecological cytology professionals regarding the concept of the simulator

We collected responses from 74 cytology professionals through a questionnaire. In Brazil, participants were from São Paulo, Rio de Janeiro, Bahia, Goiás, Maranhão, Minas Gerais, Pará, Pernambuco, and Ceará. In Portugal, responses came from Lisbon, Porto, Cascais, and Sines. Additionally, international contributions were received from Luanda (Angola), Santiago (Chile), Maputo (Mozambique), Quito (Ecuador), Lima (Peru), and Minas, Lavalleja (Uruguay). Among the respondents, 73% were female, 39% were aged between 40 and 50 years, and 27% were between 29 and 39 years old. Regarding educational background, 65% held

postgraduate degrees in cytology, 32% had undergraduate degrees, and 3% had technical training (cytotechnicians). Concerning professional experience, 51% reported practicing for more than five years, while 16% stated they had less than one year of experience. Additionally, 80% of participants reported engaging in training programs for continuous improvement. However, 40% of these professionals considered the training offered to be insufficient to fully meet the demands and challenges of their practice. These results suggest a perceived gap in continuing education, which may impact the quality of work performed by these professionals.

Regarding perceptions of the PapSim simulator, using a Likert-like scale where 10 represents "strongly agree" and 1 "strongly disagree", 50% of respondents expressed total agreement with using the digital simulator for the continuous improvement of their training. When asked whether digital tools seemed more effective as a complement compared to traditional teaching methods, 19% strongly agreed, while 10% strongly disagreed. Finally, 36% of professionals fully agreed that simulators assist in clinical practice, whereas only 2% strongly disagreed.

The data reflect that, although the majority (80%) of professionals engage in continuous training, there is still a perception that current training programs are insufficient (as reported by 40% of respondents). This finding aligns with broader concerns in the field, where the traditional reliance on physical slide-based training has been identified as a limitation. Recent advances in digital pathology have begun to address these issues, offering scalable and consistent training experiences across various scenarios. The digitization of slides enables remote access, providing a more flexible and standardized learning environment Hassell *et al*. [2023].

4.2 Prototype of the Digital Simulator

The storyboard was structured into two main scenes: sample collection and the pathology laboratory, where slide staining and microscopic analysis take place. The prototype was developed using the Unity Engine, a versatile platform created by Unity Technologies for building real-time interactive applications, including games and virtual reality. It supports cross-platform compatibility, visual editing tools, and C# scripting, allowing for rapid prototyping and iterative development. The simulation offers an average immersion time of approximately 25 minutes. On the initial screen, users begin the experience by clicking "Start", with the option to pause and resume later using "Exit" and "Continue".

The first scene occurs in the exam room. Nurse Florence introduces herself to the health undergraduate student (HUG) and explains the use of Personal Protective Equipment (PPE), including safety goggles, a mask, a lab coat, and procedural gloves. Each item is highlighted for interaction and is automatically equipped with audiovisual feedback. Once all PPE is worn, the student enters the collection room (Figure 1). To personalize the experience, the system allows the student to enter their name, email, and avatar.

Two fictional patients are then introduced. In the first case, Rosalind undergoes a conventional cytology collection under Florence's guidance. The student manipulates instruments such as the vaginal speculum, Ayre's spatula, a brush, and the glass slide used for sample smearing (Figure 2). In the second case, Mary's exam demonstrates liquid-based cytology. The student handles a detachable-tip brush and a vial containing preservative solution. Florence highlights the importance of mastering both techniques.

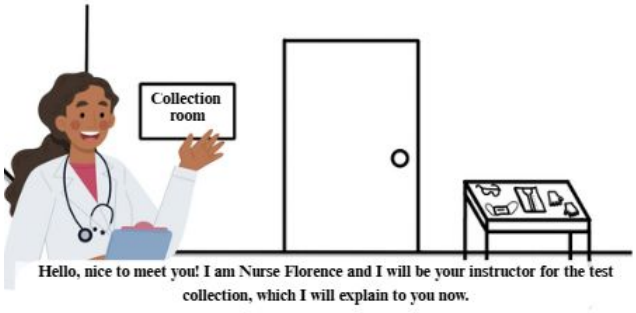

Figure 1. The initial representation of Nurse Florence introducing herself to the HUG as the instructor.

The main difference between conventional Pap smear collection and liquid-based cytology lies in sample processing and diagnostic possibilities. The conventional technique smears material directly onto a slide, which may contain blood, mucus, or overlapping cells, making microscopic analysis more challenging and limiting testing to cytology alone. In liquid-based cytology, the entire sample is preserved in a vial, preventing cellular loss and enabling both cytological analysis and HPV detection with genotyping in molecular laboratories [Assunção *et al*., 2025]. During preparation, filtration removes interfering elements, producing a cleaner slide that facilitates microscopic reading and ensures a more reliable technical report.

The second scene of the simulator takes place in the Pathology Laboratory. Professor Andrea welcomes the student and presents the available materials, including staining dishes, a fume hood, a homogenizer, a microscope, and a tray with slides. She provides step-by-step guidance for performing the Papanicolaou staining method in accordance with laboratory standards.

The subsequent subscenes focus on microscopy and the

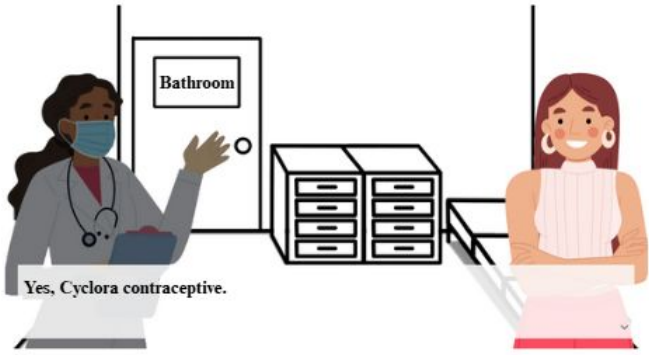

Figure 2. Nurse Florence conducts the anamnesis of Rosalind, the first patient, and asks about the use of contraceptives.

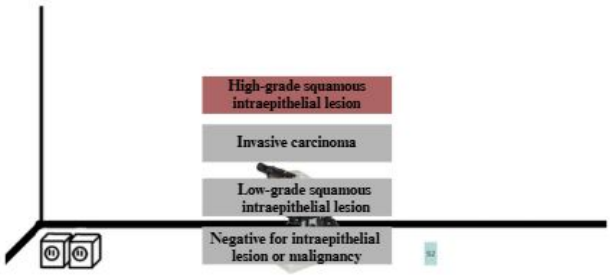

Figure 3. After analyzing the image, the HUGs could select one of four alternatives for Rosalind's technical report.

interpretation of diagnostic reports[1][2][3]. The student is introduced to the Bethesda System and must select one of four possible results: low-grade squamous intraepithelial lesion, high-grade lesion, invasive carcinoma, or negative cytology for malignancy (Figure 3). Incorrect answers prompt corrective feedback, allowing repeated attempts until the correct option is chosen. Finally, reports are reviewed and signed by the medical pathologist Henrietta.

Before large-scale validation, the prototype was tested by a small group of students, whose feedback contributed to refining the simulator's design and improving user experience.

4.3 Concept test of the Alpha version of the PapSim simulator prototype

In this initial stage, four third-year nursing students from the Federal University of São Paulo (Unifesp) participated in the simulator prototype experience. Although the sample size was limited, the objective was to gather qualitative feedback to improve the tool. The simulation sessions were recorded via Meeting, allowing observation of participant behavior. Immediately afterwards, students completed an emotional evaluation questionnaire based on the Pleasure Framework Costello and Edmonds [2007], which included 13 categories: creation, exploration, discovery, difficulty, competition, danger, captivation, sensation, sympathy, simulation, fantasy, camaraderie, and subversion. Each category was rated using an adapted Self-Assessment Manikin scale Bradley and Lang [1994], with visuals ranging from 0 ("I didn't feel it") to 5 ("I felt very"). Written justifications were encouraged to provide qualitative insights Manzano-León *et al*. [2021].

Emotional responses were predominantly positive, particularly in categories related to engagement and interaction, while danger and subversion elicited more varied reactions. Students highlighted the novelty of the method, its interactivity, and its role in supporting theoretical knowledge review. One participant reported initial confusion with the interface, suggesting that introductory guidance could improve usability.

In the Difficulty category, responses showed a mixed experience: two students selected "I felt very", one chose "I felt", and one marked "neutral". Although some participants faced challenges when answering the final questions, they perceived these moments as opportunities for self-assessment. The Competition category was also positively evaluated, with students feeling motivated by goal-oriented tasks and progressive stages, equally selecting "I felt" and "I felt very". Perceptions of Danger were more divergent: two students indicated "I didn't feel it", while one selected "I felt", and another left the category blank, noting that the simulation did not include significant risk elements. In Captivation, Sensation, and Sympathy, most students chose "neutral", although isolated responses of "I felt" were recorded. Comments suggested that the activity was engaging but could benefit from more concise text and clearer visual cues, such as color-coded containers in the second scene. The Simulation category received unanimous "I felt very" responses, with students emphasizing that the realistic virtual environment enhanced clinical preparation and theoretical content review. Feedback on Fantasy was mixed: two students marked "neutral", one "I felt", and another "I felt very", mentioning that the simplified design limited immersion in imaginative scenarios. For Camaraderie, three students selected "I felt very", and one chose "I felt", highlighting the positive interaction with the assistant character and the collaborative atmosphere. Lastly, Subversion showed varied responses: two students selected "I felt very little", one "neutral", and one "I felt very". Two participants justified not having felt subversion, while one commented, "It's great to have teaching options that move away from a traditional academic-centered model", and another stated, "Breaking rules slows down the process". In additional feedback, a student expressed, "I found the simulator amazing, a great alternative to traditional teaching methods which, nowadays, struggle to be accessible to all types of students, considering neurodivergence and disabilities". Table 1 presents the distribution of these reported feelings across the Pleasure Framework categories, with immersion times ranging from 16 to 33 minutes.

Subsequently, we held a meeting with the four students, who reported having a great experience with the simulator. They highlighted that such a tool should be used before the practical women's health course. Currently, the method employed in this course involves deliberate practice in rapid cycles (PDCR), through repetitive simulations of the same clinical case. Participants receive direct feedback and have multiple opportunities to "try again", creating multiple chances to "get it right", thus replacing the focus on long debriefings. Once the objectives of the cycle are met, a new cycle begins, with tasks of higher complexity, promoting the continuous development of the required skills [Hunt *et al*., 2014; de Castro and Couto, 2018]. In case of any errors, the student must restart the process from the beginning until they can complete the procedure according to the protocol. Hunt et al. reported that applying the PDCR method in advanced Pediatric CPR simulation training resulted in a significant reduction in the time interval between the onset of pulseless ventricular tachycardia and the performance of chest compressions and defibrillation, proving the effectiveness of the method.

A study by Wang *et al*. [2024] evaluated the use of PDCR

[1]Video 01: https://youtube.com/shorts/TC8s3I3k3bo (Accessed on September 18, 2025)

[2]Video 02: https://youtube.com/shorts/dG-wq0P7CqA (Accessed on September 18, 2025)

[3]Video 03: https://youtube.com/shorts/36Rv7M5vyWs (Accessed on September 18, 2025)

Table 1. Distribution of Reported Feelings of Four Students According to the Pleasure Framework Categories.

Pleasure Framework	I didn't feel it	I felt very little	Neutral	I felt	I felt very much
Creation	-	-	-	2	2
Exploration	-	-	-	1	3
Discovery	-	-	-	3	1
Difficulty	-	-	1	1	2
Competition	-	-	-	2	2
Danger	2	-	-	1	-
Captivation	-	-	3	1	-
Sensation	1	-	3	-	-
Sympathy	-	-	3	1	-
Simulation	-	-	-	-	4
Fantasy	-	-	2	1	1
Camaraderie	-	-	-	1	3
Subversion	-	2	1	-	1

in forceps training for gynaecology residents with no prior experience. Although it improved immediate performance, the method did not show a significant impact on skill retention after one year. Research indicates that PDCR is effective for short-term memory, but its influence on long-term memory is limited. One of the students who underwent the women's health course and experienced the PDCR method revealed feeling exposed and embarrassed as the execution took place in front of peers, and repeated errors increased nervousness during the repetitions. According to him, using the PAPSIM simulator before PDCR could provide better content assimilation, reducing the need to interrupt and repeat the process multiple times.

The Alpha version of the simulator does not yet feature a finalized design. Despite the small number of participants, the potential of the tool for teaching gynaecological cytology is already apparent. Improvements to the simulator are continually being developed, and soon, another six students from the same class, as well as five specialists in the field of cytology, will participate in the experiment with the Beta version. After evaluating the feedback and implementing the improvements suggested by the 10 students and specialists, we will begin the validation process of the digital simulator combined with the board game.

Finally, to prevent the simulated patient Rosalind from progressing to cervical cancer, students were invited to engage in the "HPV Combat" challenge (board game).

4.4 Physical Game Prototype

After completing the two scenes in the digital simulator, students who accept the challenge proceed to the HPV Combat board game (Figure 4). The board was developed using the Canva platform and starts at the Simulation and Training Center, located in the center of the board, from where players can access four distinct paths: the Primary Healthcare Unit (gray), the Molecular Research Laboratory (green), the Outpatient Treatment Clinic (pink), and the Conventional Cytology Laboratory (orange). Players represent healthcare professionals demonstrating their knowledge and decision-making skills in HPV prevention, diagnosis, treatment, and molecular research.

The game introduces a narrative element through cards

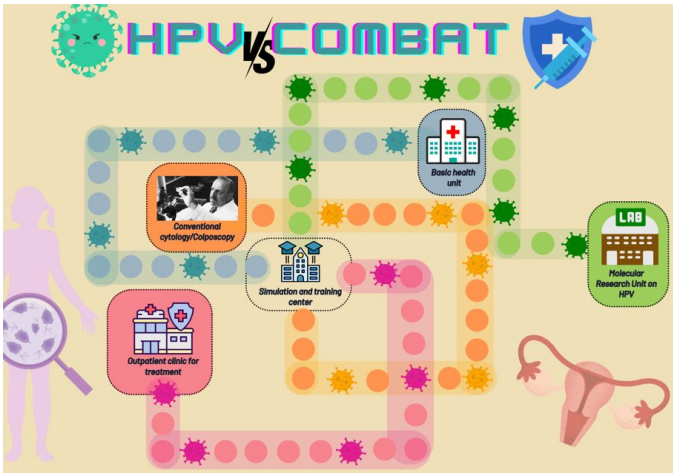

Figure 4. The 'HPV Combat' board visually represents the journey of healthcare professionals in their mission to prevent and manage HPV infection.

honoring historical female figures in science and healthcare. Henrietta Lacks, for example, had her cells removed without her consent in 1951, leading to groundbreaking medical discoveries and the development of a multimillion-dollar biomedical industry based on the immortal HeLa cell line (Figure 5). The game also pays tribute to Florence Nightingale, Rosalind Franklin, and Mary Papanicolaou (Figure 6). Students must collect four certificates, one from each path (Figure 7), to complete the challenge. The first player or team to collect all certificates wins, but the collaborative nature of the activity ensures that all participants benefit from reviewing and consolidating their knowledge as they advance through the game.

4.4.1 Game Rules *HPV Combat* Board Game

The board game consists of 35 standard cards, 21 virus cards, and 4 mixed-question cards, designed to reinforce HPV-related concepts through an engaging, interactive experience. Figures 4, 5, 6, and 7 illustrate the board layout, virus cards, example question cards, and certificates, respectively. In the following, there is the step-by-step procedures in which the player has to conduce during a game session.

1. *Starting Point:* All players or teams begin at the Simula-

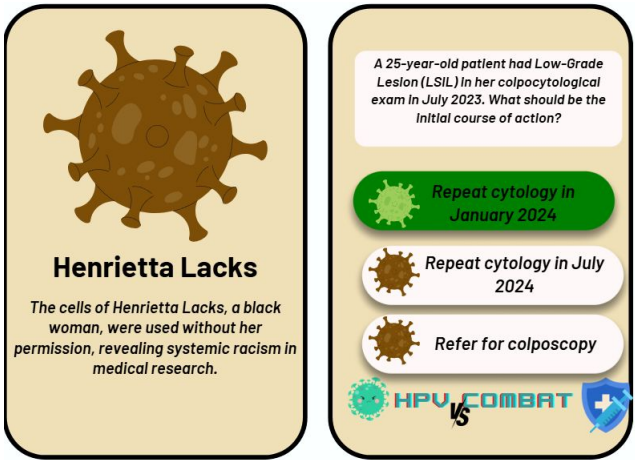

Figure 5. This represents one of the 21 virus HPV cards, with the front and back displaying a more complex clinical case challenge. In this case, the player must answer a question about a low oncogenic risk lesion.

tion and Training Center at the center of the board. The goal is to navigate through all four paths and collect one certificate from each knowledge area.

2. *Movement:* At the beginning of each turn, players roll a four-sided die (1d4) to determine the number of spaces to move.
3. *Standard Squares:* Each square corresponds to a question related to the theme of the path. Players draw a color-coded card from the 35-question deck and must answer correctly to advance.
4. *Virus Squares:* Special Virus Squares contain more complex questions (21 cards). Incorrect answers require the player to move one space back before continuing.
5. *Intersection Squares:* At intersections between two paths, the player draws one card from a set of four mixed-question cards, which include questions covering both knowledge areas. Only one card is drawn per turn when landing on an intersection square. Incorrect answers result only in losing that turn, without moving backwards.
6. *Certificates:* Upon completing all questions in a chosen path and after successfully earning that path's certificate, players must return to the Simulation and Training Center. From there, they select a new path. This process repeats until all four certificates are collected.
7. *Winning the Game:* The first player or team to collect all four certificates wins. A collective victory is achieved when all participants obtain their certificates, promoting cooperation and shared learning.

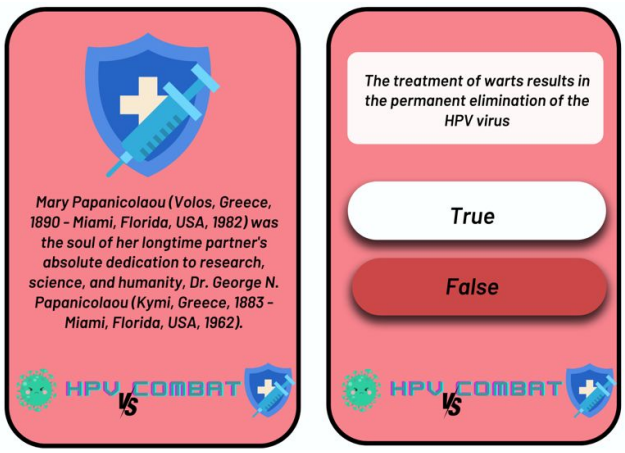

Figure 6. The figure represents one of the 35 response cards, front and back of the Outpatient Clinic for Treatment.

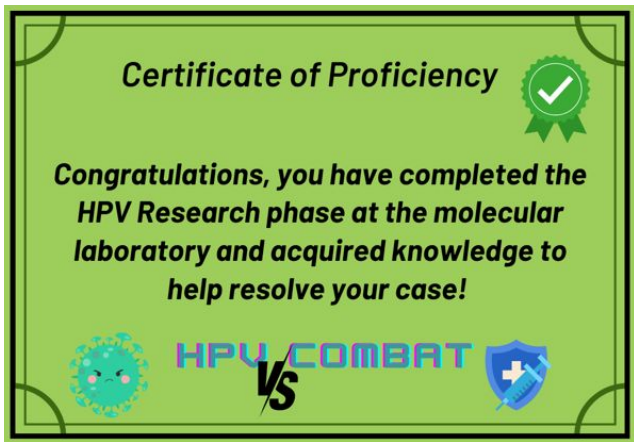

Figure 7. This represents one of the four certificates to be earned during the game.

4.5 Physical-Digital Approach

During the prototyping phase, the integration between the physical board game and the digital simulator was conducted manually. After completing the digital simulation, students who accepted the challenge proceeded to the board game under the instructor's guidance. This step-by-step transition allowed both components to be tested independently while the technical integration process was still being developed. Early tests led to adjustments in the board game mechanics, such as expanding the number of cards from 40 to 60 to balance difficulty and improve gameplay.

In the final version (to be validated in future studies), an Arduino Leonardo will work as a keyboard interface, enabling the system to recognize physical cards and display corresponding actions on the computer screen. This setup aims to mirror real-time players' actions within the digital environment, creating a seamless, interactive experience. It also lays the foundation for future experiments to validate the complete physical-digital integration of the educational tool.

The combination of the simulator and the board game was designed to merge technical learning with playful engagement. While the simulator provides a controlled environment to practice clinical reasoning, the board game fosters epidemiological thinking and teamwork. Together, they offer complementary perspectives on the prevention and management of cervical cancer. Following large-scale validation, both tools are intended to be made freely available in an open-access format, allowing educators, researchers, and healthcare professionals to integrate them into academic and training settings.

The simulator also pays tribute to outstanding women in science and healthcare. Florence Nightingale is recognized as the founder of modern nursing. Rosalind Elsie Franklin, represented as Patient 1, contributed significantly to the discovery of DNA's structure through her work in X-ray crys-

tallography. Mary Papanicolaou, represented as Patient 2, played a role in the development of the Pap test. Henrietta Lacks, depicted as a pathologist, made an involuntary yet pivotal contribution to biomedical research through the HeLa cell line. Lastly, Professor Andréa Malinverni of the Federal University of São Paulo is honoured for her work in health education and academic ethics. These figures symbolize the transformative impact of women on scientific and medical advancements.

Although only the simulator was tested with students in this phase, feedback from four third-year nursing students highlighted its potential to enhance learning in women's health. The experience reinforced the importance of simulation-based strategies to complement traditional teaching methods. While integration with the board game was under development, these early-stage tests mark progress toward a comprehensive physical-digital educational solution [Germano da Silva *et al*., 2024b].

Other studies have demonstrated the benefits of hybrid game-based approaches in fostering engagement and learning. For example, Silva *et al*. [2024] developed a combined board and digital game for teaching Computer Networks, demonstrating that hybrid formats can enhance motivation and knowledge acquisition. This interdisciplinary evidence supports our proposal, reinforcing that combining physical and digital tools can provide more dynamic and inclusive learning experiences across various educational contexts.

The integration of physical and digital components in the "HPV Combat" game promotes an immersive and well-rounded educational experience. The board game encourages players to explore epidemiological aspects of HPV, such as transmission, prevention, and treatment, while the digital simulator focuses on clinical procedures and diagnostic processes. In their study, Germano da Silva *et al*. [2024a] observed that few healthcare studies consider both physical and emotional dimensions when implementing new technologies. The dual-modality approach proposed here addresses this gap, offering learners a broader and more integrated understanding of HPV and cervical cancer, preparing them to face complex public health challenges more effectively.

The perceptions of gynaecological cytology professionals and third-year nursing students in this study further highlight the value of the digital simulator as a strategy to enhance continuous training and complement traditional methods. Students also emphasized its innovative nature, suggesting its use before practical sessions in the women's health course to improve content assimilation. Although still under development, the Alpha version has shown promising results, and improvements are underway based on feedback. Findings from Hipólito et al. (2024) support these results, indicating that technology-enhanced learning tools hold significant potential for health education.

5 Study limitations

During the prototyping phase, only four students participated in the initial testing of the digital simulator, and the integration with the board game was conducted manually. Importantly, the board game itself and its combination with the simulator were not formally evaluated at this stage. Therefore, the findings refer solely to the students' interaction with the digital prototype. Since the simulator relies on internet access and the availability of electronic devices, its implementation requires appropriate infrastructure. Moreover, adapting the board game to various educational settings presents additional challenges. To address these limitations, the research team proposed the possibility of renting equipment in coordination with institutional teaching schedules. Given that most campuses already provide internet access, this strategy would facilitate the simultaneous use of both tools in future trials.

6 Conclusion

This study reinforces the importance of teaching pathology within health science programs, especially for addressing cervical cancer prevention. Although the digital simulator was tested with only a small group of students, it yielded valuable insights by analyzing emotional responses through the Pleasure Framework. This affective assessment was the most explored aspect of the prototype, revealing the relevance of emotions such as creation, exploration, discovery, and simulation in fostering student engagement and supporting the development of clinical reasoning.

By examining how students feel while interacting with the simulation, this study contributes to the understanding of learning as an affective as well as a cognitive process. The findings emphasize that emotionally engaging tools can enhance student-centered education, particularly in areas where pedagogical approaches and updated resources are limited.

While the integration between the physical and digital components is still in progress, the positive affective responses observed suggest the promise of this approach. Future work should focus on refining the prototype and expanding its implementation in broader contexts, aiming to improve public health training through innovative and empathetic educational practices.

Additionally, the insights from cytology professionals highlight significant gaps in current training and reinforce the potential of the digital simulator as a strategy for continuing education. By promoting technical updates and more interactive methodologies, the tool can benefit both formal education and the ongoing development of practising professionals, ultimately enhancing the quality of healthcare services.

6.1 Future Work

The next steps of this project involve the integration of an automated system using Arduino, which will enable more efficient interaction between the physical and digital components of the educational tool. This automation aims to enhance interactivity and provide a more immersive and engaging learning experience. Once the prototype is complete, validation with both experts and students will be essential to assess the perceived improvements in each component, the board game and the digital simulator. These evaluations will be conducted in classroom or laboratory settings, allowing

for feedback from the target audience on the effectiveness and usability of the physical-digital combination. Additionally, future studies will investigate knowledge retention, offering a deeper understanding of the educational impact of the developed tools and their potential to support more effective training strategies in the healthcare field.

Declarations

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Authors' Contributions

AGdS: Conceptualization; Methodology; Validation; Investigation; Writing. GSG: Software development. LM: Physical board game design; Validation. BRG: Software development. LDAR: Data curation. MATS: data curation. CL-S: Methodology. ALB: Technical supervision, Writing - technical review. ACdMM: Technical supervision, Writing - technical review.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The project will be available at https://encurtador.com.br/5B8IL (accessed 18 September 2025).

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