Upgrading MatematiX: A Modern Approach to Learning Geometry for Middle School Students

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Keywords: Geometry Software App, middle-school Students, Gamification, Serious Games.

Abstract: The paper presents an upgrade version of our previous application MatematiX. The software has been upgraded with additional features designed for middle school students (grades 5–7), emphasizing the development of geometric reasoning skills necessary to address mathematical problems related to geometric figures. The upgrades contain an instructional module on angles and their characteristics, presenting a visual explanation of angle definitions, sequential guidance for angle measurement, and an interactive game that involves students in angle measurement using a virtual protractor. The application was validated by a group of 70 middle school students. Their feedback was overall positive, mentioning that the app helped them understand angles and their measurement, even before formal classroom instruction, underlining its efficacy as a resource for early geometry teaching.

1 INTRODUCTION

In a continuously digitalized environment, the educational process must adapt to fulfill the requirements and anticipations of today's learners. In this sense, technology can significantly enhance learning, especially in areas that are frequently seen as difficult, such as geometry (Cahya and Indriana, 2023). Middle school students in Romania in their fifth, sixth and seventh years sometimes have difficulties comprehending geometric concepts, potentially resulting in diminished interest and performance in the subject (Moral-Sánchez et al., 2022).

Geometry, an essential discipline of mathematics, cultivates logical reasoning, problem solving abilities, and spatial cognition. Traditional pedagogical approaches, predominantly dependent on textbooks and lectures, often lack the engagement and interactivity necessary to captivate the attention of current digitally native middle school students. Consequently, interactive educational applications that facilitate geometry learning through visual, tactile, and stimulating approaches have to be incorporated (Abdan Syakuran et al., 2022).

The material, which is intended for fifth, sixth, and seventh grade middle school students, can effectively reinforce knowledge and promote a natural comprehension of geometric ideas. It can enable the transition from repetition to active learning, providing a tailored experience that enhances middle school students' curiosity and inventiveness. In this context, the development and implementation of novel digital solutions is important in order to upgrade the educational process in Romania.

The incorporation of gamification and narrative techniques in the development of a geometry application for Romanian middle schools is relevant, as it fulfills essential educational requirements by improving engagement, motivation, and conceptual comprehension. Gamification components, like prizes and interactive challenges, enhance student engagement and ongoing participation, whilst storytelling offers context and relatability, aiding students in comprehending intricate geometric concepts through narrative-based learning experiences. Collectively, these methods foster a dynamic, learner-centered environment that corresponds to contemporary instructional approaches and enhances the cultivation of critical thinking and creativity (Butean et al., 2015).

The paper presents an improved iteration of MatematiX (Popita and Coroiu, 2024) incorporating interactive angle measurement tools and instructional modules, which have been validated by middle school students for efficacy in early geometry education.

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Popita, D. and Coroiu, A. M.
Upgrading MatematiX: A Modern Approach to Learning Geometry for Middle School Students.
DOI: 10.5220/0013357000003932
In *Proceedings of the 17th International Conference on Computer Supported Education (CSEDU 2025) - Volume 2*, pages 800-807
ISBN: 978-989-758-746-7; ISSN: 2184-5026

2 STATE OF THE ART

Current advancements in educational apps for geometry exhibit considerable promise for changing conventional teaching methodologies. By incorporating advanced features such as interaction, personalization, and gamification, these solutions respond to the varied learning requirements of students (Pambudi et al., 2022).

Educational technology has produced multiple projects aimed at enhancing geometry education. Globally, platforms like GeoGebra, Khan Academy, and Brilliant have been recognized for their impact on mathematics education.

GeoGebra 1 is an open-source software extensively utilized for the exploration of mathematical ideas via dynamic visuals. It enables students to handle geometric forms, execute transformations, and resolve issues interactively, so rendering abstract topics more comprehensible (Hohenwarter and Hohenwarter, 2002).

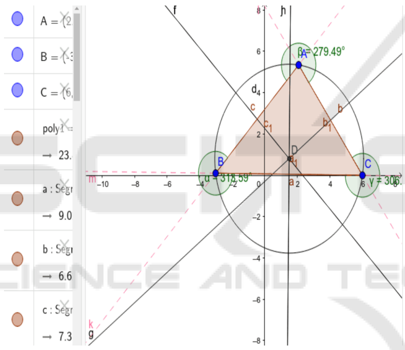

Figure 1: Geogebra APP.

Khan Academy 2 provides a systematic program in mathematics, featuring interactive lectures, videos, and practice tasks designed for different grade levels. It underscores sequential elucidations to facilitate understanding (Prensky, 2011).

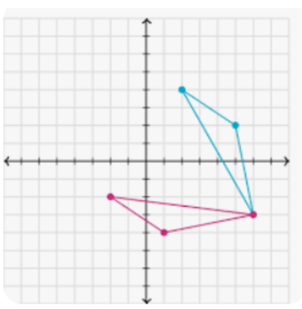

Figure 2: Khan Academy APP.

Brilliant 3 emphasizes problem solving and conceptual comprehension by offering challenges and circumstances that demand critical thinking and the use of geometric principles (Liljedahl et al., 2016).

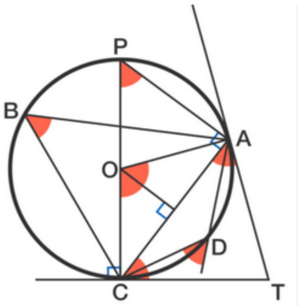

Figure 3: Brilliant App.

These platforms exemplify the efficacy of integrating visual learning, interactive activities, and personalized feedback that enhance mathematical thinking. Nonetheless, their content and structure are frequently generalized and may not correspond to particular country curricula, such as Romania's educational framework for middle school geometry.

The present state of research offers substantial evidence for the importance of software applications in enhancing geometry education. These tools augment learning via interactivity, motivation, and personalization, while assisting educators in providing successful instruction. For these applications to realize their full potential, they must conform to the curriculum, tackle accessibility concerns, and offer extensive assistance for educators (Yan, 2023).

The paper (Moral-Sánchez et al., 2022) presents Recent societal transformations necessitate that education adapts to the digital natives of the 21st century. These modifications demand a shift in the existing educational paradigm, wherein active methodologies and ICT serve as instruments for attaining this objective by formulating comprehensive teaching sequences that incorporate STEM techniques to facilitate student learning. This article presents a didactic idea in geometry centered on STEM fields through a gamified approach. This idea integrates resources such as AR, VR, tactile materials, and social networks with methodologies such as m-learning, cooperative learning, and flipped learning, facilitating methodological transformation. The study was conducted over two academic years within an action research framework. It diverged from a conventional approach, and through two cycles, the technique was enhanced by the advantages that gamification offers to STEM initiatives in Secondary Education. Data collected throughout the experiment were analyzed using a mixed-method approach. The outcomes of learning, implemented techniques, achievements, and mistakes, along with the findings of a questionnaire, are delineated. Evidence indicates a transition from a 50% failure rate to a 100% pass rate in academic performance. The majority of students exhibited increased motivation, with full group engagement. Over 80% demonstrated pleasant emotions, and cooperative learning enhanced group cohesion (Moral-Sánchez et al., 2022).

Research by Jones (Jones, 2013) demonstrates that interactive geometry software enhances spatial reasoning and conceptual understanding. By visualizing and manipulating geometric shapes, students develop a deeper comprehension of abstract concepts. The dynamic nature of such tools fosters engagement, particularly in middle school learners who benefit from visual and experiential learning.

Research conducted by Hamari and Koivisto (Koivisto and Hamari, 2019) demonstrates that gamification components, including points and prizes, markedly enhance student motivation and engagement in educational activities. This method is especially efficacious for geometry, where interest frequently diminishes due to the subject's apparent complexity.

According to Kovanović (Brooks et al., 2023), adaptive learning systems enhance learning results by customizing content to align with students' capabilities. Geometry programs that monitor progress and modify difficulty levels offer tailored feedback, allowing students to learn at their own speed and pinpoint specific areas for enhancement.

Singh and Misra (Mishra and Singh, 2021) assert that educational software incorporating teacher resources, such as automated grading and lesson planning, improves instructional efficiency. Educators can utilize these traits to discern student challenges and formulate targeted solutions, thereby enhancing the efficacy of geometry instruction.

Gutiérrez et al. (Gutiérrez and Penuel, 2014) emphasize the necessity of connecting educational software with the school curriculum. Applications developed with national standards are more likely to be embraced by educators and effectively incorporated into classroom instruction.

Valverde and Garrido's (Valverde-Berrocoso et al., 2020) study identifies challenges including restricted access to technology, inadequate digital literacy among educators and learners, and opposition to transformation within conventional teaching settings. Confronting these obstacles is essential for the effective deployment of geometry software.

Serious games are games designed for more than just pure entertainment. Used in all kind of fields nowadays, serious games are created for mastering certain skills. while playing a serious game, the user can develop or reinforce knowledge while having an entertaining and interactive experience. These kinds of games have proven their efficiency for preschool and primary education, not only in learning Mathematics, but other subjects too. For example reading, writing, strategic abilities, problem solving, creativity, science, geography and so on as described in the paper (Papanastasiou et al., 2017).

Playing games is seen as a recreational activity by most students who struggle to learn the traditional way and consider it a burden. That means that serious games could spark their interest in learning by creating fun games that help them assimilate and exercise the learned notions through play. This aspect is crucial, as the more students engage in a learning activity, the better their academic achievements may be. That is the main reason why even if developing games for all the academic curricula might seem as an unnecessary long struggle, it is a worthwhile endeavor.

A game in itself, increases the level of involvement of the user, allowing them to be spontaneous, test different outcomes without a physical punish-like consequence. They have the possibility to play a game multiple times, which increases their knowledge in the subject that the serious game is trying to teach. This way the calm and mental cognition with which a real life situation will be faced is developed; the user is conscientious that a real life situation can have multiple outcomes and that they have to discover the best solution to solve the problem faced.

A study conducted in Greece, Portugal and Italy (Barbieri et al., 2021) discovered that serious games can increase students motivation, and deepen their understanding of math concepts. The researchers developed a serious game, CLASH OF WIZARDRY, which was tested in all three countries, with around 400 students. The process showed that a carefully developed serious games, properly aligned with the curricula, would be valuable tools for supporting the educational process. The study did not only influence the STUDENTS, but also the teachers, some of them retaught their way of teaching mathematical subject after taking part in the experiment.

The experiment also proved that this kind of application would need efforts from the teachers, it would be necessary for them to find a way of integrating these types of materials in the teaching process.

3 TECHNICAL IMPLEMENTATION

The application architecture has not changed since the first implementation of the app. The application follows the classic Server-side web application architecture using c# for the API with Microsoft SQL Server and Html, JavaScript and CSS for the interface.

We mention here one of the main HTML5 elements used by our application, the `<canvas> ... </canvas>` tag. This element represents the base for drawing all the elements for the games and explanations using JavaScript code.

Elements are being redrawn on the canvas, at a certain speed or are scheduled to be drawn at a certain time during the animation in order to create a smooth look for the animation using different functions specific for the canvas element.

We have redesigned the colors in the application interface to ensure that the resources can be used by people with various visual impairments. For this we used the feature Accessibility tools provided by Adobe Color website.

4 THE NEW SET OF FEATURES INTRODUCED IN THE APPLICATION: MatematiX

We decided to add some new features to our Matematix application for the older pupils, mostly for middle school students (5th, 6th, 7th grade). We approached the subject of geometry, given the fact that for learning geometry, children have to develop a geometric way of thinking in order to be able to solve mathematic exercises with geometric figures.

We created a new set of features for the educational unit that defines angles and their properties: a visual explanation of the definition of an angle, offering instructions for how to correctly measure an angle and a game that tests the process of measuring angles using a protractor.

4.1 First Feature: The Angle. Definition and Properties

This webpage consists of a visual explanation of an angle following the definition: An angle is formed from two half-lines that extend from the same point of origin.

When users first arrive on the webpage, an animation is triggered that shows two lines moving to the center of the canvas. After the lines have both reached the center, their commune origin, the point O, appears on the screen, and the now half-lines grow for a brief moment in the opposite directions of O in order to demonstrate that because they are half-lines, they can each grow infinitely from the fixed point.

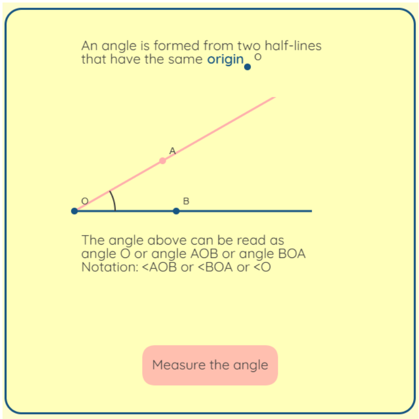

Figure 4: Explanation - first part.

At the end of his grow animation, point A appears on the first half-line and point B appears on the second half-line. Following the end of the animation, a text is written on the canvas that presents possible names and notations for the drawn angle, and a button with the text ”Measure the angle” appears under the written text.

If the user clicks on the mentioned button, the previously written text is erased and another text appears above the drawn angle that instructs the user how to correctly measure the angle. The angle that was present in the previous animation remains on the screen, and the mouse is transformed into a protractor (see Figure 5) that can be used to measure angles with values from 0 to 360 degrees. The user can now use the protractor to measure the angle.

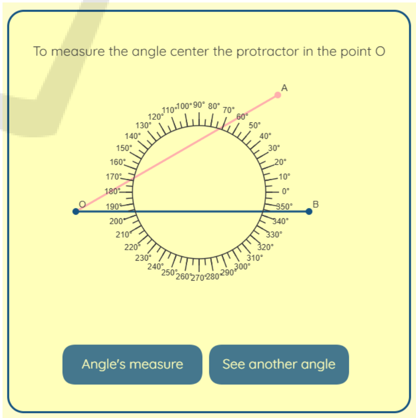

Figure 5: Explanation - measure shown.

There are two other buttons present on the screen; one with the text ”See the angle’s measure” and another one with the text ”Measure another angle”. If the user clicks on the first button, the measure of the drawn angle is shown on the screen. If the user clicks on the second button, a new angle is drawn having another measure, and the user can use any of the two buttons (see Figure 5).

4.2 Second Feature: ”Find the Enemies”

On this webpage, the users have access to a game called ”Find the enemies”. The purpose of this game is to test the user’s knowledge on how to correctly find and read the measure of an angle using a protractor.

To start the game, the user needs to click on the ”Start” button (see Figure 6). The interface of the game looks like a radar, the screen is darken, and the user can move an aim, like a ray of light, using the mouse. The aim moves in a circular manner. There are a number of monsters that move to the center of the screen (the number of monsters and their speed varies depending on the level). To win the level, the player has to hit all the monsters before they reach a certain distance from the center of the circle.

Figure 6: Game’s first screen.

There is also a protractor drawn as shown (see Figure 7) that can help the user measure the angles correctly. The player can see the number of targets that are left, the level, and the score in the top left corner. There are two types of level for this game that alternate while the user has not lost the game. One level gives for each monster angle measurements in degrees (see Figure 7). The user has to correctly position the center of the aim at that angle in order to see the monster. If the aim is centered correctly, the user can press the spacebar and the monster disappears. For the other kind of level, the player must find the monster using the aim, read the angle from which the monster is coming from, write the measure in the signaled input box and press Enter (see Figure 8). If the provided measure is correct, the monster disappears. The game goes on with these two kinds of levels until one of the monsters is at a certain signaled distance from the center of the circle and the game is lost.

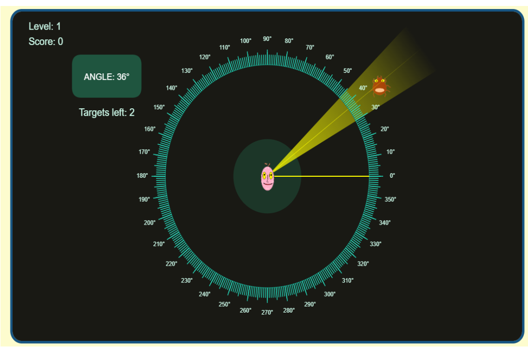

Figure 7: Given angle measure.

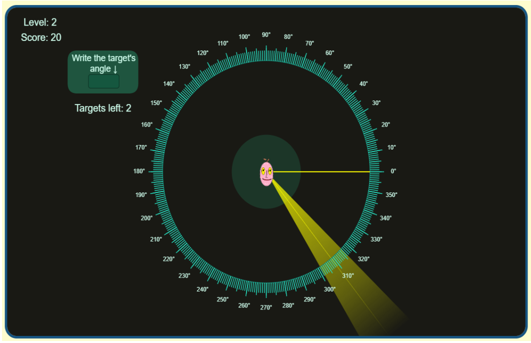

Figure 8: Angle measure has to be written.

As for the previously designed games, there is a score table where the players can see the top 5 scores obtained in the game with the username of those who got them. The children are motivated to play the game to get higher on the leader board.

5 VALIDATION OF THE NEW FEATURES

5.1 Describing the Process

To validate the application, we tested it with 70 children from the school Ion Agârbiceanu from Alba Iulia. We had two fifth-grade classes, two sixth-grade classes, and one seventh-grade class. In total, we had 70 children test the application.

We used the Smart board to project the application in order for the whole class to see it. We chose a volunteer from each class to come and play with the explanation (measure angles with the protractor, look at other types of angles, check if they have measured it correctly etc.) while the other children watched and answered questions about the presented geometry notions.

Then the children came one at a time to the laptop in front of the class and played the game. Some of the children came in pairs, one of them would look for the right angle measure on the Smart board while the other one would write the correct angle in the input box.

After using the application, each child had to answer the following questions:

- How would you rate the application from 1 to 5?
- How would you rate the navigation process on the application from 1 to 5?
- Did the application help you understand an angle's properties and measure angles using a protractor?
- What would you change/add to the application?
- What other mathematical subjects would you like us to approach in the future?

5.2 Results

An Excel document with the children's answers was generated at the end of the testing process.

For the first question, "How would you rate the application from 1 to 5?" (see Figure 9) 90% of the children rated it 5 out of 5, 9% 4 out of 5 and 1% 3 out of 5. Most of the children considered the application very exciting and enjoyed interacting with it. The answers to the second question "How would you

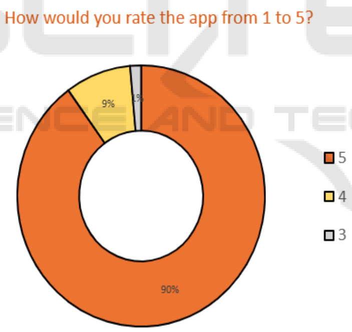

Figure 9: Application rating.

rate the navigation process on the application from 1 to 5 ?"(see Figure 10) were similar to those of the first question, 89% of the children said that it was easy to navigate the app.

All children said that the game and explanation helped them understand what an angle is and how to correctly measure it. This result is especially important because the angle is a mathematical unit that is learned only at the end of the fifth grade and the fifth graders said that they now know how to measure an angle, even if they have not learned that before interacting with our application.

When asked "What would you change to the application?" 60% of the children said that they like the application as it is. The remaining percentage

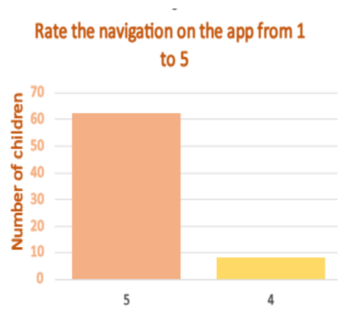

Figure 10: Navigating the app.

wanted different enemies for the game, or wished for the game to be harder, or for the game to include more geometrical subjects.

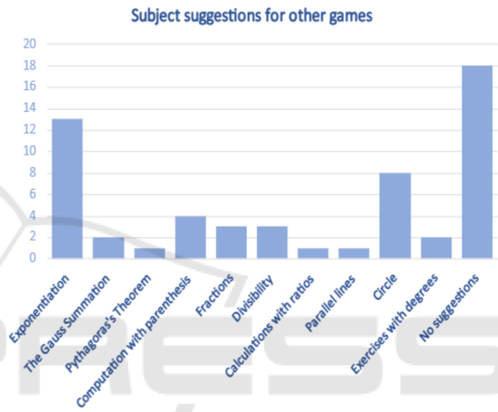

Figure 11: Suggestion's chart.

6 SWOT ANALYSIS: THE SIGNIFICANCE OF A GEOMETRY INSTRUCTION APPLICATION IN ROMANIA

For the question "What other mathematical subjects would you like us to approach in the future?", we represented the answers in a chart (see Figure 11). The answers were: The Gauss Summation, Fractions, Divisibility, Calculations with Ratios, Computation with Parenthesis, Pythagoras's Theorem, the Circle, parallel lines, Quadrilaterals, Calculations with Degrees etc. The children noted that they would see the use of this kind of software in helping them learn those notions.

The children managed to play the game very well, after a few tries they even reached higher levels. The teachers also considered the game and the explanation interesting.

The use of a geometry teaching application for Romanian middle school students presents several advantages that could substantially improve the educational experience. A key advantage is the interactive nature of these applications (Zaharin et al., 2021), enabling dynamic visuals and real-time exercises that enhance comprehension of geometric ideas. The incorporation of gamification aspects within the application may enhance student engagement and motivation. Moreover, the software's personalization and flexibility features provide the adjustment of information to individual learning levels while monitoring progress, enabling teachers to efficiently identify and solve students' weaknesses. Such tools provide significant assistance to educators by supplying preconstructed resources and automated assessment capabilities, thereby conserving time and improving instructional efficacy. Furthermore, the program guarantees access to current, curriculum-compliant information, incorporating contemporary pedagogical methods that promote innovation in educational settings. A notable asset is its capacity to enhance students' digital competencies, preparing them for a technology-oriented future.

Considering these positives, specific drawbacks must be recognized. Economic and infrastructural obstacles provide considerable difficulties, as not all educational institutions or households have access to the necessary technology or dependable internet connectivity. Moreover, numerous schools in Romania have deficiencies in the technological infrastructure required for the effective integration of such technologies (Durach et al., 2021). Digital literacy constitutes a constraint, as certain educators and learners may encounter difficulties in utilizing the program, necessitating investments in training and adaptation. Excessive reliance on technology may lead students to depend excessively on the application, thus limiting their capacity to solve impediments manually or comprehend concepts profoundly. Moreover, if the application's content does not entirely conform to the national curriculum, it may be considered irrelevant or inadequately utilized by instructors.

The external environment offers numerous options for the effective execution of a geometry teaching application. The growing utilization of digital tools in education in Romania creates a conducive environment for the integration of such software. This transformation is helped by governmental and European Union programs designed to enhance digital infrastructure in educational institutions, including funding prospects for execution. The increasing significance of STEM education underscores the necessity of a geometry-centric tool, as geometry cultivates essential abilities like spatial reasoning and problem-solving (Moral-Sánchez et al., 2022). Parental support for interactive and contemporary teaching tools is growing, highlighting the potential acceptability of such an application. Partnerships with local educational authorities, non-governmental organizations, and educational technology firms offer additional avenues for promoting extensive adoption and integration.

Nevertheless, specific outside threats can affect the execution and efficacy of any project. Economic discrepancies among various locations may intensify the digital divide, marginalizing some student demographics and fostering inequity in educational access. Resistance to change from educators and parents favoring conventional education techniques constitutes a notable impediment. Moreover, programs that gather and analyze student data may encounter examination under GDPR and other privacy standards, requiring stringent compliance requirements. Technological complications, such application failures or device incompatibility, may lead to customer displeasure. Ultimately, the existence of other educational applications, including established foreign alternatives, may restrict the market adoption of a newly launched application.

7 CONCLUSIONS

After improving and testing our application, we concluded that a geometry teaching application for middle school students in Romania has significant potential to update and enhance the educational process. The children and teachers who participated in the testing exercise found the application useful and engaging, which is an encouraging result.

However, the success of this type of software hinges on overcoming both internal and external constraints. A concentrated strategy will be necessary to address infrastructure and training obstacles, synchronize content with curriculum, and ensure compliance with data protection requirements.

Additionally, the teacher's involvement and willingness to try this kind of software are essential for its successful implementation and integration in the educational system.

Furthermore, capitalizing on opportunities such as digital education trends and collaborative partnerships can promote the extensive adoption and efficient use of the program, ultimately revolutionizing the teaching and learning of geometry in Romania.

8 FUTURE WORK

Following the results of this experiment, we found how we can better our application. First, because we saw an interest for this kind of software from older children (5th, 6th, 7th grade) we wish to create more resources for them, centered on the needs that they brought up while testing the application (see Figure 11).

Secondly, we would like to make the application adaptive to any kind of screen so the children are be able to use it on their phones too.

We also wish to further research how we can best integrate artificial intelligence into our application and what other features we would be able to introduce with the help of AI.

Moreover, we want to improve our current resources based on the feedback received so far. One of the improvements would be to add sounds in the games and more visual animations.

Last but not least, we want to test both existing features and future developments in various educational contexts that involve more Romanian schools. A solution for this would be to deploy the application and link it with a complex feedback form that teachers and students would fill out after using the application. Enough support from different schools and teachers would be much needed.

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