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Implementation and evaluation of AR games and tools in Greek primary Schools through the process of the design and creation of a Rubric by the students

Nikolaos Amanatidis [1*]

[1] Regional Directorate of Primary Education of Eastern Thessaloniki, Thessaloniki, GREECE
***Corresponding Author:** nikosaman@gmail.com

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ABSTRACT

The following research paper presents a comprehensive evaluation of augmented reality (AR) games and educational tools, hence AR games, implemented in the Greek primary education system, focusing on the design and creation of a graded criteria scale (Rubric) for selecting and evaluating AR educational games–applications utilized by the students. The study aims to determine, through evaluation approaches, the basic criteria for developing an effective Rubric, by the students, on specific issues such as the main functionality and effectiveness of the games in regard to cognitive areas and skills development, steered through these AR applications. A mixed-method approach was adopted, employing qualitative and quantitative analyses, assessing AR tool utilization in classroom settings, and evaluating the applications' educational impact. The study entails collecting data from AR tool usage in Greek primary schools and the design and construct, by the students, of a Rubric based on educational and functional effectiveness. This Rubric provides a framework for assessing various aspects of AR educational games, such as Educational Value, Content Quality, Design, Usability, and Technical Features. Key findings include AR games' effectiveness in enhancing student engagement, understanding, and retention of information through interactive experiences. A notable facet is the integration of student input in Rubric creation, which contextualizes the evaluation process within the cognitive and developmental scope of primary education learners. Four case studies detail practical implementation and evaluation of selected AR applications: *Mondly* for English language learning, *Clever Book AR Geometry*, *Google Expeditions AR* for ocean exploration, and *Banun Ruang AR Geometry* for 3D geometry comprehension. The cases highlight the educational benefits of the specified AR games, such as visualization, active and kinesthetic learning, fostering motivation and collaboration. Constraints discussed include limitations in sample size, geographic reach, device type, and infrastructure barriers. Despite these boundaries, the study proposes a structured model for evaluating and effectively integrating AR games into educational practices, signaling a shift towards STEM-enhanced learning environments.

Keywords: AR, augmented reality in education, augmented reality educational games, instruction, evaluation, focused literature review

INTRODUCTION

As technology continues to advance, augmented reality (AR) games, hence AR, are increasingly being surveyed as a means of enhancing teaching and learning in various educational settings, including Greek primary education (Elkoubaiti & Mrabet, 2018). AR refers to a technology that allows the integration of virtual objects into the real world, creating an interactive and immersive learning experience for students. AR can be a powerful tool for learning in the classroom. With AR apps, students can access projection-based, location-based, and detection-based experiences that make objects, artifacts, or media appear to exist in the actual room. They can interact with the content by moving around, getting closer to it, and manipulating it to engage in learning experiences about it (Antonioli et al., 2014; Chang et al., 2010; Geroimenko, 2020). Several studies have examined the use of AR games in educational settings and have highlighted their potential benefits for students (Brizar & Kažović, 2023; Kozov & Ivanova, 2023; Shaukat, 2023). For instance, the use of AR games can promote active engagement and participation among students, as they can manipulate virtual objects and explore concepts in a more engaging and interactive manner. Additionally, AR games could enhance students' understanding and retention of information, as they provide a visual and kinesthetic learning experience suited for differentiated instruction and multimodal teaching and learning. Students can create their own AR experiences to demonstrate their understanding of a concept. They can use critical thinking, problem-solving, and communication skills to explore the lesson or an activity. AR can be integrated into all grades and subjects, from exploring space and the environment to learning about animals and creating book reviews or historical settings. Furthermore, AR games can also raise collaboration and

teamwork among students, as they can work together to solve problems and complete virtual tasks. Likewise, AR games can provide personalized learning experiences, as they can adapt through providing differentiated instruction modes and strategies to individual students' needs and pace of learning (Ghobadi et al., 2022; Murseli et al., 2022; Rakshit et al., 2023).

In today's age of digital worlds and identities, this new generation of students, often called "digital natives" (Prensky, 2001), as well as the "net generation" (Tapscott, 2008), or "gamer generation" (Beck & Wade, 2004) is increasingly using (Eurostat, 2015; Lenhart, 2015) digital games and devises in their leisure time (Mascheroni & Ólafsson, 2013; Ofcom, 2014), for various activities such as entertainment, communication and learning (Lenhart, 2015; Ofcom, 2014; Perrin, 2015).

A notable part of the younger generation's engagements with these smart digital devices are the digital games and tools. These games are also called 'mobile games' (Koutromanos & Jimoyiannis, 2022), they usually enter the hitherto familiar classifications of games such as simulation, discovery and adventure games (Kirriemuir & McFarlane, 2004) and are either installed on the devices, downloaded to them or played online in conjunction with other users-online friends. In addition, another category of app-games, called AR Apps, are played on these new smart devices. In a review by Koutromanos et al. (2015), it is portrayed that AR games, when exploited under specific learning conditions in formal and informal learning environments, can provide a positive effect on learning and the development of complex skills.

THE SURVEY

The existing research aims to answer a set of following questions, through the observation of educational applications of AR in primary school classroom settings in Greece, an educational system comparable to other European countries such as Portugal, Italy and Spain, and also based on the educational principles, policies and directives of the European Union specifically in the field of AR games. In addition, to define the framework for the creation of a scale of graded criteria (Rubric) for their evaluation and effective implementation of specific AR games in the daily educational process (Alexiadou et al., 2022; Jahic & Pilav-Velic, 2022). The following questions are requested to provide appropriate responses regarding the research in discussion:

1. What cognitive areas and skills using AR games is the existing research focused on?
2. What is the pedagogical background as well as Greek educational environment on which the design and implementation of AR games can be based?
3. What kind of evaluation would take place on the games?
4. What are the axes on which the creation and implementation of the scale of graded criteria (Rubric in **Appendix A**) evaluation will be based?
5. What kind of methodology will be followed in terms of the type of survey, sample and data collection games for the educational implementation and evaluation of the games?

Methodology for Implementing AR Games in the Greek Primary Education Setting

It is important to address the issue of methodology for effectively integrate selected AR games in the Greek primary education setting (Koutromanos & Jimoyiannis, 2022; Rellia, 2022). Thus, to effectively implement AR games in Greek primary education, a comprehensive methodology is needed. This methodology could include the following steps:

1. **Conducting a needs analysis:** This step involves identifying the specific educational goals and objectives that can be achieved through the utilization of AR games. This can be done through brainstorming discussions with teachers, and other stakeholders in the Greek primary education system.
2. **Developing an adjusted and flexible curriculum framework:** Once the needs analysis is complete, a curriculum framework should be developed to outline how AR games will be integrated into existing instructional practices. This framework should include information on the specific AR games that will be utilized, the learning outcomes that will be targeted, and the assessment methods that will be operated to measure student learning.
3. **Designing AR learning activities:** Based on the new and adjusted curriculum framework, specific AR learning activities should be designed. These activities should align with the learning objectives and engage students in interactive and immersive experiences.
4. **Implementing AR learning activities:** Once the AR learning activities are designed, they should be implemented in or outside of the classrooms. This can be done by providing the necessary setting and support for teachers to effectively use AR games, ensuring access to the required technology infrastructure, and monitoring the implementation process to address any challenges or issues that may arise.
5. **Evaluating the effectiveness of AR games:** After the implementation of AR learning activities, it is important to evaluate their effectiveness in achieving the desired educational outcomes. This can be done using qualitative and quantitative data collection methods, such as observations, interviews, and student assessments. To successfully evaluate the effectiveness of AR games in Greek primary education, a graded criteria scale could be created for selecting and evaluating AR educational games by the students.

Methodology for Design, Creation, and Implementation of the Evaluation Rubric

The methodology for formulating the scale of graded criteria (Rubric) is proposed to be implemented in three axes. This methodology was based on previous research that developed Rubrics in the information and communication technologies field, and particularly those that focused on mobile device applications (Green et al., 2014; Papadakis et al., 2017).

Researchers around the world have set various standards for constructing a graded criteria scale (Rubric) (Allen & Tanner, 2006; Moskal, 2000; Roblyer & Wiencke, 2003). More specifically, a Rubric should include an appropriate and optimal number of criteria. When the number of criteria is too large, the Rubric becomes dysfunctional, and when the number of criteria is small, the Rubric does not provide sufficient information about the evaluation item. There should also be functional criteria and performance descriptions. In addition, the scoring scale should range from (1) one for the worst performance to (4) four for the best. Performance descriptions should be as detailed and comprehensive as possible (Papadakis et al., 2017).

The axes on which the construction of the graded criteria scale (criteria, levels, quality ratings, and scoring strategy) is to be based, are as follows:

1. **Educational research and literature review:** Early evidence suggests that children can learn from well-designed educational applications. Children learn best when they are cognitively active and engaged, when learning experiences are meaningful and socially interactive, and when learning is guided by a specific goal (Hirsh-Pasek et al., 2015). Educational applications should provide primary opportunities for children to create their own content and engage in a rich and dynamic learning process (Kucirkova et al., 2015).
2. **Application rating scales:** In recent years, several application assessment games have been developed (Lee & Cherner, 2015). In our view, most of the categories that have been studied and proposed lack the specificity needed to evaluate this new form of technology or do not emphasize all the characteristic data required for an effective educational application that is relevant to primary school children of the current era and the educational environment of the modern Greek education setting, These assessment games , like the one developed by Lee and Cherner (2015), fall short when it comes to evaluating educational applications designed for young children in the modern Greek context. These games tend to suffer from two main drawbacks:
    a. Lack of specificity and an inadequacy in addressing the distinctive needs of the Greek educational environment: Primarily, existing categories used for app evaluation are often too broad. For instance, a category like “design” might encompass a total from visuals to user interface. This fails to apprehend the specific design elements that are crucial for engaging young learners, such as the use of interactive features, age-appropriate animation styles, or the clarity of instructions presented for Greek students.
    b. These games often miss important aspects specific to educational applications for young children such as environment, infrastructure, curriculum, and in class collaboration strategies.
3. The third axis of the study concerns the **evaluation of AR applications-games by teachers** in cooperation with students. It concerns the apps that are available at the time of the research in the Apple Store and Google Play that are specifically targeted for children of a certain age at the time of the study.

According to Lee and Cherner (2015), the Rubric ratings and associated categories are presented in **Table 1** under three main headings.

Table 1. Rubric evaluation and the relevant categories

Teaching design	Design	Student engagement
Dynamic	Ability to store progress	Learner control
21st century skills Integration	Platform of completion	Interactivity
Links to future learning	Screen design	Pace
Value of errors	Ease of use	Personal preferences
Feedback to teacher	Navigation	Interest
Level of learning material	Target orientation	Aesthetics
Cooperative learning	Media integration	Usability
Adjustment of individual differences	Cultural sensitivity	

For each axis, there is an associated question in the form of the main question, which must be answered. The header for each dimension assigns five indicators on the Likert scale, which answer the ways in which the functionality or design of an application answers that question (Lee & Cherner, 2015).

In conclusion, while existing app assessment games offer a starting point, they lack the necessary depth and focus to accurately evaluate educational applications designed for young children in the modern Greek educational context. By incorporating more specific evaluation criteria that consider factors like age-appropriateness, cultural relevance, and alignment with the curriculum, we can develop games that provide a more comprehensive picture of an application’s effectiveness for young learners in specific learning environments.

Therefore, considering the relevant literature and based on the findings of the applications’ evaluations; to effectively judge the quality of educational AR games for primary school children in today’s Greek educational experience, we propose the following four key areas: education, content, design, usability, and technical features. The stages of development of the graded criteria scale (Rubric) for AR games in today’s Greek educational setting through specific case studies follows.

IMPLEMENTATION PROCESS–THE DESIGN AND CREATION OF THE EVALUATION RUBRIC–THE ACTUAL CASES

The author observed and interviewed four elementary school teachers in their in-class implementation and evaluation of selected, by the teachers AR games, and evaluated by the students through the formation of a Rubric. The project focuses on a

two- branched approach: Teacher implementation and student-driven evaluation. First, the teachers implemented selected AR educational games and applications within their classrooms. Second, the research forwards to the design and creation of a graded criteria scale by the students themselves. This student-created Rubric assessed certain factors like accessibility, usability, design, and trustworthiness of the AR games. By analyzing both teacher implementation experiences and student evaluations, the research aims to provide valuable insights into the effectiveness and suitability of AR games for enhancing learning in Greek primary schools.

1. The English teacher from the English language experimental primary school, approach: Utilizing AR and student-led evaluation for English language learning through the **Mondly** AR application.

This analysis portrays the implementation of an AR tool called Mondly for English language learning in a 5th grade classroom. Furthermore, it explores student participation in designing an evaluation Rubric to assess the app's effectiveness. Mondly was selected as the AR tool for implementation based on its features, user-friendliness, and compatibility with educational needs. The justification for choosing Mondly is provided, including its interactive modules, gamified learning environment, and potential to increase student engagement and motivation.

Participants

The participants were a class of 25 5th grade students (age range: 10-11 years) from a Greek public elementary school. All students had access to iPads provided by the school.

Procedure

The study followed an eight-step process:

1. **Introduction of Mondly AR:** The teacher introduced the Mondly AR app on their iPad, showcasing its functionalities for learning English. Prior to the implementation, a training phase was conducted where the teacher familiarized himself with Mondly's functionalities as well as the students. The training included navigating the app, utilizing its features effectively, and integrating it into lesson plans. The teacher was also trained in how to guide students in understanding the evaluation process as well as designing the evaluation Rubric.
2. **App installation:** Students downloaded the Mondly app onto their individual iPads with the teacher's guidance.
3. **App exploration:** Students were granted two class periods to explore the app functionalities and learning activities independently and in small groups. The implementation phase involved introducing Mondly to the 5th grade students and working with Mondly in subjects of the actual current curriculum of the 5th grade class. The teacher integrated Mondly sessions into the regular curriculum, ensuring that students engage with the AR tool during language lessons. The use of Mondly was systematically recorded, noting frequency, duration, participation of students, effective usability, results, and the type of activities performed.
4. **Soliciting student feedback:** To incentivize participation and create a sense of agency, the teacher informed the students that their feedback would be crucial for the lesson and themselves in deciding whether to continue using the application.
5. **Student-led brainstorming:** Students were divided into small groups of four to five (overall approximately a hundred students from the four case studies participated in the research) to brainstorm questions related to their experience with the Mondly AR tool. These questions addressed specific aspects such as ease of use, content relevance, compatibility, appropriateness, engagement level, and learning effectiveness.
6. **Collaborative Rubric development:** The brainstormed questions were presented on the board. The teacher facilitated discussions, categorizing questions based on theme and ensuring clarity. Students then voted on the questions they considered most important for evaluating the application.
7. **Evaluation Rubric creation:** Based on the voted-upon questions, the teacher guided the students in creating a final evaluation Rubric (Rubric 2 in **Appendix B**). This Rubric contained clear criteria and scoring scales to assess the application's effectiveness from the students' perspective. Students learn to assess their own progress and the effectiveness of Mondly in meeting their learning goals. Certain challenges were a few technical issues such as connectivity.
8. **Tool evaluation:** Finally, students individually completed the co-created, ten parameter, evaluation Rubric (Rubric 2 in **Appendix B**). providing feedback on their experience with the Mondly app.

Representative statements by the students follow:

> Mondly AR is a very helpful software to learn new languages. It is a real teacher in front of you! I love it!
>
> The free version has only a few basic stages then you must buy the rest. It is user friendly and helpful.
>
> Mondly AR makes learning languages so interactive and enjoyable. It's a nice app for students who want to break away from boring textbooks!
>
> If you're looking for a fun and effective way to learn a new English, I suggest you try this tool.

Representative statement by the teacher follows:

> Mondly AR truly enhances language learning by bringing virtual teachers right into your space. It's like having a personal tutor guiding you through each lesson process.

2. The primary school teacher from the experimental primary school connected to the university–faculty of pedagogy. Implementation and evaluation of the "**Clever Book AR Geometry**" application.

Analytical Look: Using Clever Book AR Geometry for 5th Grade Geometry

The Clever Book AR Geometry (**Appendix C**) offers a promising approach to enhance geometry learning in a 5th grade classroom consisting of 24 students from different backgrounds such as economic migrants and middle-class families. A breakdown of its practical implementation, considering participation, learning, instruction, evaluation and potential challenges following.

Participation and learning enhancement

1. **Visualization:** The specified AR tool allowed students to directly manipulate 3D shapes on their devices. This active engagement fostered spatial reasoning and a deeper understanding of geometric concepts compared to traditional 2D representations. As a result, we experienced full class participation as well as understanding shapes and properties of the Geometric forms by all the students, even the indifferent ones.
2. **Kinesthetic learning:** Rotating and exploring the shapes from different angles catered to the kinesthetic students who benefited from a hands-on approach. This led to a more holistic understanding of the shapes.
3. **Motivation:** The interactive nature of the specific tool increased engagement and motivated students to explore Geometry. The teacher argued that it transformed a potentially boring subject into a fun and interactive experience.

Instructional methodology

1. **Differentiation:** The application accommodated autonomous learning, allowing students to explore shapes at their own pace in groups or individually. This, as indicated, is beneficial for students with varying learning styles and abilities.
2. **Collaboration:** Group discussions, after independent exploration, encouraged peer-to-peer learning. Students shared observations, leading to a deeper understanding and the identification of any misconceptions.
3. **Assessment:** Quizzes and interactive elements within the app utilized formative assessment. This affordance allowed the teacher to monitor progress and identify areas where students might need additional support.

Evaluation–Student-designed Rubric

The student-created Rubric focused on access, usability, design, and trustworthiness and provided a valuable insight for evaluating the app's effectiveness.

It is important to note that the teacher did not impose a direct proposal to the students on the Rubric issue. The teacher in the whole process adopted the role of a mentor and a guide with a sole purpose of fostering ideas and creativity to the students into the design and creation of the Rubric. The steps trailed by the students in collaboration with the teacher follow:

1. **Identifying criteria:** The students initially began by brainstorming the key factors that contribute to an app's effectiveness. This included considering how easily they can access the app, how spontaneous its usability is, how aesthetically pleasing its design is, and how trustworthy the information or functionality it provides.
2. **Defining levels of performance:** Once the criteria were identified, the students proceeded, discussing the different levels of performance for each criterion based on a Likert scale.
3. **Assigning weights:** Depending on the importance of each criterion, the students have assigned weights to reflect their relative significance in evaluating the app's effectiveness. For instance, the selected criteria in each Rubric were designated by the importance of the application to the specific student as well as the lesson they were involved in.
4. **Testing and revising:** After drafting the Rubric, the students tested it by applying to other similar apps so as to ensure its effectiveness and reliability. Through this process, they have identified areas where the Rubric needed adjustment or clarification and made revisions accordingly.
5. **Finalizing the Rubric:** Once the Rubric was refined based on testing and feedback, the students have finalized it for use in evaluating the specific AR tool as well as other similar games such as geometry AR.

By following these steps, and according to the teacher's interview statements, the students have created a comprehensive and practical Rubric for evaluating the effectiveness of the AR tool based on access, usability, design, and trustworthiness. As indicated by the teacher and the student in the in-class observation "This Rubric can serve as a primary tool for assessing and improving the quality of educational AR games in similar lessons and subjects".

An analysis of each factor follows:

1. **Access:** According to students, the overall functionality and connectivity of the application was assessed to participate fully.
2. **Usability:** Evaluated the app's ease of use. The intuitive interface. Functional design and clear instructions for students to navigate the app independently and effectively.
3. **Design:** Considers the app's visual appeal and engagement. The practical and performing design that can hold students' attention and facilitate learning.
4. **Trustworthiness:** The functionality and accuracy of the games and information presented in the app.

Potential challenges as indicated by the students:

1. **Connectivity issues:** A weak internet connection can hinder the AR experience.

2. **Functionality issues:** Technical glitches or app malfunctions can occur. A troubleshooting plan or backup activities can help alleviate this issue.
3. **Device discrepancies:** Students may have devices with varying functionality and capabilities. Teachers should be aware of these and tailor activities accordingly.

Conclusion

The Clever Book AR Geometry app has the potential to significantly enhance geometry learning in a 5th grade elementary classroom according to the teacher's and the students' viewpoint. By incorporating instructional strategies like differentiation and collaboration, coupled with a student-designed Rubric to evaluate the app's effectiveness, teachers can create a rich learning environment that fosters deeper understanding and active participation for all students. Being aware of potential challenges and having backup plans can ensure a smooth learning and teaching experience.

Representative statements from the students follow:

> The app was very interesting, and I have learnt to use it efficiently in 20 minutes time!
>
> The app was quite functional although we had a few cases of slow response due to the bad Internet connectivity.

3. The primary school teacher at a public school. Implementation and evaluation of the "**Google Expeditions AR**" application tool.

Exploring the oceans through AR. Corals are an important ecosystem in the oceans. They provide food and a home to many species of marine organisms. Raising students' awareness of the importance of conservation and protection of these ecosystems.

Lesson Objectives

1. Understanding the importance of the oceans as ecosystems and a source of life.
2. Familiarization with the threats facing the oceans, such as global warming, pollution, and loss of biodiversity.
3. Encouraging awareness of ocean conservation and protection.

Introduction.

The lesson initiated with a discussion on the role of the Ocean s in life on Earth. Following a presentation of the threats facing the Oceans and another dialogue and discussion on the importance of coral reefs and their role in the Ocean. Furthermore, the students argued about the risks they face due to climate change, Ocean warming and other factors. All students' responses were noted.

Application in the classroom

The teacher utilized the interactive platform to provide a virtual experience with corals, such as a tour of the cean floor, virtual tour of the underwater world and marine life. Showcasing the beauty of coral reefs and the dangers they face. Followed a group discussion and debate about the experience of exploring the virtual reality of the seafloor. Additionally, an analysis of the problems experienced by the oceans and a further discussion of the role of climate change and the responsibility of human influence and activity.

Creating a wall of ideas

The lesson plan included the creation of an idea wall (Padlet App) with a list of suggestions on how we can contribute to coral reef conservation. The students create da Padlet with a list of risks such as global warming and pollution threats highlighting the importance of reefs for global ecology and fish life. An action plan to protect the oceans was discussed and suggested. Certain challenges involved connectivity issues.

The evaluation Rubric

The students with the teacher's guidance created and completed the application's evaluation Rubric where they illustrated their thoughts and proposals as well as the rating on a (5) five-point Likert scale of the AR application, on terms of functionality, transfer of knowledge and engagement.

Representative statements from the students follow:

> We could create posters and notify the community not to pollute the sea and the Oceans.
>
> We should not throw rubbish in the sea!

4. The primary school teacher at a public school. Implementation and evaluation of the "**Banun Ruang AR Geometry**" application tool.

Perception

This application consists of an interactive AR tool where the user is controlled by the teacher. The users in the specific case are elementary school students from grade 5. The purpose of this application is modelling 3-dimensional spaces for a geometry lesson. Regarding the appearance of the specific application, it confers to the learning methodology and curricula of elementary

schools, which includes initiation, prior discussion, and formative assessment of the transfer of knowledge and skills to the students. It regards modeling of 3-dimensional spaces through a full color design and appearance which in general students at elementary school age are interested and engaged.

Learning affordances of the application:

1. **Visualization:** Through the applications implementation the Teacher could identify and enhance students' ability to visualize and understand 3D shapes and spaces.
2. **Collaboration:** The teacher through group organizing and workspaces encouraged full student participation and collaboration through group-led exploration of 3D models.
3. **Formative assessment:** Integration of formative assessment practices to measure student understanding throughout the lesson.

Instructional Procedure

The students utilized the app, operating tablets for every group manipulating a 3D model on the screen. Rotated and zoomed in/out on the model, highlighting key features like faces, edges, and vertices.

The teacher acted as a facilitator, guiding students through exploration and promoting active participation. She also guided and encouraged student research and criticality by asking questions throughout and adopted a formative assessment process.

Application design considerations: Regarding the shape and full-color design. The app's use of full-color visuals aligns with elementary school learning methodologies. It caters to the visual learning styles of students and keeps them engaged.

Simplicity: The interface should be simple and natural, with well-defined controls for the teacher. Avoid overwhelming students with complex app features.

Benefits of the utilization of the application according to the teacher were, active learning of the students involved in the learning process as researchers and collaborators through interaction and discussion and not passively attending a presentation. Also adopting differentiated instruction practices through diverse learning styles with visual representation and interactive elements.

The challenges that teachers faced were technical Issues such as technical glitches or connectivity problems that could disrupt the lesson. Classroom management issues such as maintaining focus and engagement during exploration and activities.

Evaluation Rubric: The students, with the teacher's guidance, created and completed a Rubric focused on specific issues of the application regarding access, usability, design, and trustworthiness. Thus, they provided a valuable tool for evaluating the app's effectiveness.

Conclusion: By utilizing Banun Ruang AR Geometry creatively, teachers can transform a traditional geometry lesson into an interactive and engaging experience. The combination of teacher-facilitated exploration, formative assessment, and a well-designed class and app-based working environment can significantly enhance students' understanding and appreciation of 3D space modeling through AR application learning and teaching.

Representative statements by the students follow:

> The application is interesting and engaging. We learnt a lot about geometric shapes.
>
> The application is very interesting, if only we could turn and throw the object away it would be more helpful and interesting.
>
> Wow! That game was super fun! I didn't even realize I was learning about shapes while playing.

Representative statement by the teacher follows:

> This AR interactive tool captivates and educates the students by providing an immersive experience that deepens understanding of geometric shapes.

Table 2 summarizes the AR games, the school environment, the Rubrics and the challenges that took place in the study. Also, a representative scan of each Rubric is in the **Appendix D** section of the article.

Table 2. Summary of the study's cases

AR tool	School	Grade	Lesson	Rubric	Challenges
Mondly	Experimental primary school of English	5th	English	Clear criteria and ten parameter scoring scales	Technical issues and connectivity
Clever Book AR Geometry	Experimental primary school	5th	Mathematics	Access, usability, design, and trustworthiness	Connectivity & functionality issues & device discrepancy
Google Expeditions AR	Public primary school	5th	Environmental education	A 5 Likert scale of the AR application on terms of functionality, transfer of knowledge, and engagement	Connectivity issues
Banun Ruang AR Geometry	Public primary school	5th	Mathematics	Access, usability, design, and trustworthiness	Technical & classroom management issues

DISCUSSION AND CONCLUSIONS

The conclusion of this research underlines the strategic importance of a vigorous evaluative framework for AR games within the Greek primary education system. Our findings have established a comprehensive graded criteria scale, specifically a Rubric, that has been designed and personalized by the students themselves. This framework not only validates the utility and effectiveness of AR games but also highlights their considerable influence on learning outcomes and student participation and motivation. The study has demonstrated, through a collection of case studies regarding AR games that specialize in learning domains such as English as a foreign language, geometry, and the natural sciences, that AR's interactive paradigm is influential in fostering an active and engaging learning environment. The interactive and experiential nature of AR draws students into modus that traditional methods have often failed to achieve, leading to enhanced understanding and retention of knowledge. Resonating with the ethos that education must be active learner-centered, this research marks a significant step forward, ensuring the empowerment of primary students by entrusting them with the games to critically evaluate the educational games and applications that influence their learning journey.

The study's outcomes resound well with existing academic discourse on AR games in education, acting as a complementary chapter in the evolving narrative of immersive technology in learning settings. The literature consistently highlights AR's potential to revolutionize classroom dynamics by nurturing a fertile ground for collaboration among students (Elkoubaiti & Mrabet, 2018; Geroimenko, 2020). Indeed, our findings show AR games not only foster collaborative efforts but also resourcefully adapt to the distinct learning styles and paces of individual students, thereby offering a tailored educational experience–one that is both collective and personal. Such dual facilitation is reflective of the powerful mediating role AR can play, creating a symbiotic ecosystem where technology meets pedagogy. It substantially elevates the quality of interactive learning, supporting the premise that the incorporation of AR games into the curriculum can both enrich the learning journey and equip learners with essential 21st century skills. As our study merges with these observations, it further substantiates the positive impact of AR on individualized learning experiences, aligning seamlessly with broader international research trends that employ AR's potential to transform pedagogical practices and outcomes.

The relevant study was not devoid of constraints, principal among them being a limited sample size, the diversity of participating schools, the variability in types of supporting devices, and the span of technological infrastructures. Recognizing these limitations was essential for constructing a realistic and transferable educational model. Efforts to exceed these challenges involved adopting a flexible framework that could accommodate different school contexts, and ensuring compatibility across various platforms, from iOS to Android. This universality ensures that the created Rubrics were not only tailored to the conditions of the study but is also aware for adaptation and potential adoption across a multitude of educational landscapes. Transparent acknowledgment of these constraints not only encouraged the study's integrity but also mapped a path for subsequent activities to pilot these and other emergent obstacles, thus paving the way for more effective, inclusive, and technology-enriched learning environments.

Looking to the future, this study lays the foundation for subsequent explorations in the evolving field of AR in education. It is essential to recognize the dynamic nature of AR technologies and the continuous emergence of advanced applications that could further revolutionize learning experiences. Follow-up studies are vital to test the strength and adaptability of the evaluation Rubrics presented in this paper, ensuring its relevance and effectiveness as new AR applications will be present. Moreover, as our preliminary findings suggest a significant impact of AR games within STEM subjects, it would be wise to expand the use of the Rubrics beyond these areas. To embrace the full potential of AR in education, the Rubrics could be refined and extended to cover a wider range of subjects and inter-disciplinary undertakings. This inclusivity will cater to diverse learning needs and inclinations, ultimately paving the way for a more comprehensive, technology-enhanced education that echoes with learners across the entire educational spectrum.

In conclusion, this study represents a significant step in the field of AR in education, particularly within the Greek primary educational context. It has constructed a comprehensive framework not only for assessing the impact of AR games on learning outcomes but also for involving students in a meaningful evaluation process of the games they are using. It is an innovative effort that collides with the participatory nature of modern education, where learner engagement and interaction with digital games are paramount. The study underscores the potential of AR to foster a deeper understanding and increase motivation among students, an aspect that is critical in the pursuit of a sustained educational reform. However, the true vitality of AR in education lies in its continuous evolution. As such, there is a call to action for educators, researchers, developers, and policymakers to persist in their exploration and refinement of AR applications. Additionally, the student created Rubrics, designed for evaluation, could be subject to regular implementation and reevaluation to keep pace with technological advances and new pedagogical insights. Furthermore, the implementation of AR technology in the classroom signifies a shift towards more engaging and interactive teaching methods. By utilizing AR evaluation Rubrics, students and teachers can select and create dynamic learning experiences that capture students' attention and promote active participation. The use of AR games allows for a greater degree of individualized instruction. With the aid of the designed Rubric, teachers and students can select applications that cater to the unique learning styles and needs of each student, fostering a more inclusive and effective learning environment. Additionally, selected and evaluated AR games can facilitate collaborative learning experiences, promoting teamwork and effective outcomes among students. By selecting and implementing together AR environments, students can share ideas, solve problems, and enhance knowledge and skills from one another in novel and engaging ways.

The journey of perfecting AR as an educational tool is perpetual, and the present study contributes to laying down the tracks for future empirical studies, curriculum design, and policy decisions, ultimately enriching the educational landscape. We cannot isolate children from technology, but we should in any case ensure that they are not negatively affected by it (Ebbeck et al., 2016).

As Parette et al. (2010, p. 2) state regarding the ever-increasing technological applications available to students, the question is not only whether technology should be appropriately evaluated and used in educational settings, but also how it can make a difference to the effective learning, skill cultivation and wider development of the students' personalities and talents in today's rapidly evolving 21st century society.

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Ethical statement: The author stated that, before initiating this study on using augmented reality (AR) games in primary school classrooms, the project was clearly explained to both the students and their parents or guardians, making sure everyone understands what's involved and that participation is completely voluntary. The author further stated that all information is treated with the utmost care — names and personal details will never be made public, and all data will be stored securely. Because AR technology is new and exciting, special attention was paid to making sure it's safe, appropriate, and accessible for every child. The goal was to create a fun, supportive, and respectful environment where every child felt included and valued, and where their privacy and safety are always protected and respected.

Declaration of interest: No conflict of interest is declared by the author.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the author.

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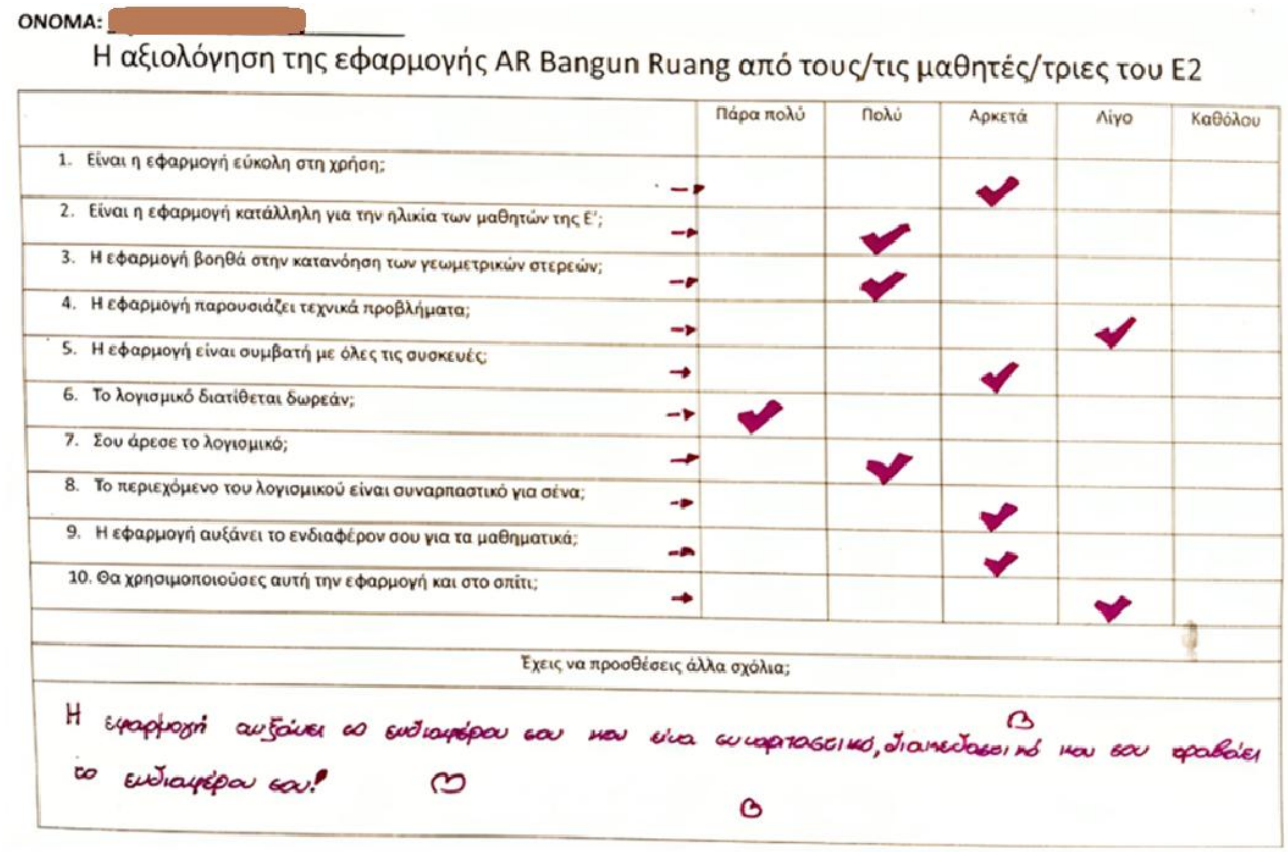
APPENDIX A: REPRESENTATIVE RUBRICS FROM EACH SCHOOL CASE-1



ΟΝΟΜΑ: [redacted]

Η αξιολόγηση της εφαρμογής AR Bangun Ruang από τους/τις μαθητές/τριες του Ε2

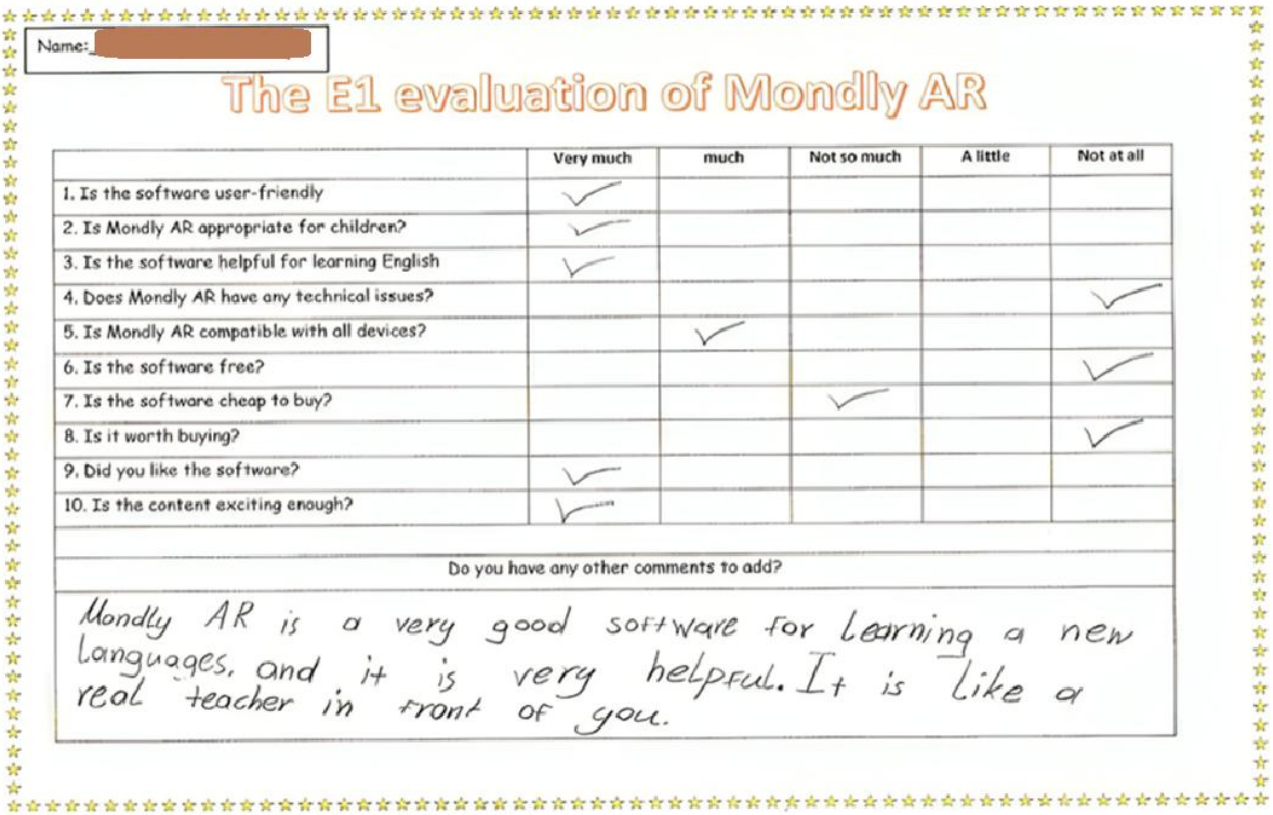
	Πάρα πολύ	Πολύ	Αρκετά	Λίγο	Καθόλου
1. Είναι η εφαρμογή εύκολη στη χρήση;			✓		
2. Είναι η εφαρμογή κατάλληλη για την ηλικία των μαθητών της Ε';		✓			
3. Η εφαρμογή βοηθά στην κατανόηση των γεωμετρικών στερεών;		✓			
4. Η εφαρμογή παρουσιάζει τεχνικά προβλήματα;				✓	
5. Η εφαρμογή είναι συμβατή με όλες τις συσκευές;			✓		
6. Το λογισμικό διατίθεται δωρεάν;	✓				
7. Σου άρεσε το λογισμικό;		✓			
8. Το περιεχόμενο του λογισμικού είναι συναρπαστικό για σένα;			✓		
9. Η εφαρμογή αυξάνει το ενδιαφέρον σου για τα μαθηματικά;			✓		
10. Θα χρησιμοποιούσες αυτή την εφαρμογή και στο σπίτι;				✓	

Έχεις να προσθέσεις άλλα σχόλια;

Η εφαρμογή αυξάνει το ενδιαφέρον σου που είναι ψυχαγωγικό, διασκεδαστικό και σου φτιάχνει το ενδιαφέρον σου!

Figure A1. Rubric 1. Banun Ruang AR Geometry comprehension (Source: Field study)

APPENDIX B: REPRESENTATIVE RUBRICS FROM EACH SCHOOL CASE-2



Name: [redacted]

The E1 evaluation of Mondly AR

	Very much	much	Not so much	A little	Not at all
1. Is the software user-friendly	✓				
2. Is Mondly AR appropriate for children?	✓				
3. Is the software helpful for learning English	✓				
4. Does Mondly AR have any technical issues?					✓
5. Is Mondly AR compatible with all devices?		✓			
6. Is the software free?					✓
7. Is the software cheap to buy?			✓		
8. Is it worth buying?					✓
9. Did you like the software?	✓				
10. Is the content exciting enough?	✓				

Do you have any other comments to add?

Mondly AR is a very good software for learning a new languages, and it is very helpful. It is like a real teacher in front of you.

Figure B1. Rubric 2. Mondly for English language comprehension (Source: Field study)

APPENDIX C: REPRESENTATIVE RUBRICS FROM EACH SCHOOL CASE-3

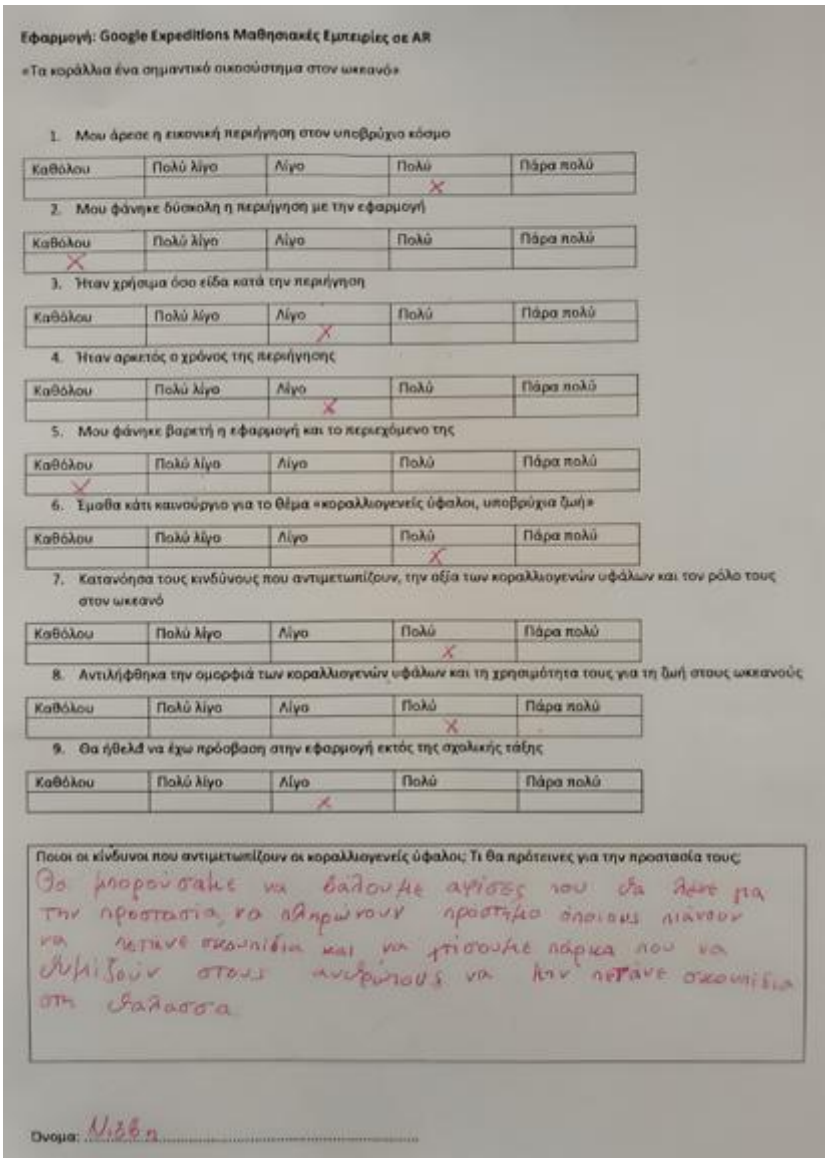
Όνομα μαθητού/τριας: [redacted] Ημερομηνία 7/2/22

Αξιολόγηση της εφαρμογής Clever books AR Geometry!

	1	2	3	4
Πρόσβαση στην εφαρμογή	Η εφαρμογή αξιοποιήθηκε ελάχιστα λόγω της ασυμβατότητάς της με την κινητή συσκευή και της κακής σύνδεσης στο ίντερνετ.	Η εφαρμογή εμφάνιζε αρκετές δυσλειτουργίες κατά τη χρήση είτε λόγω της κινητής συσκευής που χρησιμοποιήθηκε είτε λόγω της κακής πρόσβασης στο ίντερνετ.	Η εφαρμογή ήταν αρκετά λειτουργική χωρίς να επηρεάζεται από την πρόσβαση στο ίντερνετ ή την κινητή συσκευή που χρησιμοποιήθηκε.	Η εφαρμογή AR ήταν απολύτως λειτουργική χωρίς να επηρεάζεται από την κινητή συσκευή ή το ίντερνετ.
Ευχρηστία	Μου πήρε περισσότερο από 60' για να κατανοήσω τη λειτουργία της εφαρμογής.	Μου πήρε περίπου 40 λεπτά, για να μάθω να χειρίζομαι την εφαρμογή αποτελεσματικά.	Μέσα σε 20 λεπτά έμαθα να χειρίζομαι αποτελεσματικά την εφαρμογή, αλλά ζήτησα και τη βοήθεια της κυρίας μου.	Μέσα σε 20 λεπτά έμαθα να χειρίζομαι την εφαρμογή χωρίς καμία βοήθεια.
Χρησιμότητα εφαρμογής	Η εφαρμογή δεν ήταν καθόλου ενδιαφέρουσα και λειτουργική. Ήταν αδύνατη η κατανόηση των γεωμετρικών εννοιών που παρουσιάζονταν και τα γραφικά ήτα φτωχικά.	Η εφαρμογή δεν ήταν αρκετά ενδιαφέρουσα και λειτουργική. Επίσης, δεν μπορούσα να κατανοήσω τις γεωμετρικές έννοιες που παρουσίαζε.	Η εφαρμογή ήταν πολύ ενδιαφέρουσα, λειτουργική, με ωραία γραφικά αλλά δεν ανταποκρινόταν αρκετά στον τρόπο που μου αρέσει να μαθαίνω.	Η εφαρμογή ήταν πολύ ενδιαφέρουσα, λειτουργική, με ωραία γραφικά και ανταποκρινόταν στον τρόπο που μου αρέσει να μαθαίνω.
Αξιοπιστία	Η εφαρμογή δεν λειτουργούσε (κολλούσε) όταν γινόταν ταυτόχρονη χρήση από τους/τις μαθητές/τριες της τάξης.	Η εφαρμογή λειτουργούσε με αρκετές προσπάθειες που έκανα, για να ξεκολλήσει και να μπω στο περιβάλλον της.	Η εφαρμογή λειτουργούσε και υπήρξαν λίγες φορές που κόλλησε ή αντιμετώπισα πρόβλημα.	Η εφαρμογή λειτουργούσε άριστα και δεν κολλούσε ποτέ.

Figure C1. Rubric 3. Clever Book AR Geometry (Source: Field study)

APPENDIX D: REPRESENTATIVE RUBRICS FROM EACH SCHOOL CASE-4



Εφαρμογή: Google Expeditions Μαθησιακές Εμπειρίες σε AR

«Τα κοράλλια ένα σημαντικό οικοσύστημα στον ωκεανό»

1. Μου άρεσε η εικονική περιήγηση στον υποβρύχιο κόσμο

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
			X	

2. Μου φάνηκε δύσκολη η περιήγηση με την εφαρμογή

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
X				

3. Ήταν χρήσιμα όσα είδα κατά την περιήγηση

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
		X		

4. Ήταν αρκετός ο χρόνος της περιήγησης

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
		X		

5. Μου φάνηκε βαρετή η εφαρμογή και το περιεχόμενο της

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
X				

6. Έμαθα κάτι καινούργιο για το θέμα «κοραλλιογενείς ύφαλοι, υποβρύχια ζωή»

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
			X	

7. Κατανόησα τους κινδύνους που αντιμετωπίζουν, την αξία των κοραλλιογενών υφάλων και τον ρόλο τους στον ωκεανό

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
			X	

8. Αντιλήφθηκα την ομορφιά των κοραλλιογενών υφάλων και τη χρησιμότητα τους για τη ζωή στους ωκεανούς

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
			X	

9. Θα ήθελα να έχω πρόσβαση στην εφαρμογή εκτός της σχολικής τάξης

Καθόλου	Πολύ λίγο	Λίγο	Πολύ	Πάρα πολύ
		X		

Ποιοι οι κίνδυνοι που αντιμετωπίζουν οι κοραλλιογενείς ύφαλοι; Τι θα πρότεινες για την προστασία τους;

Θα μπορούσαμε να βάλουμε αφίσες που θα λένε για την προστασία, να πληρώνουν πρόστιμο όποιοι πιάνουν να πετάνε σκουπίδια και να φτιάξουμε πάρκα που να μιλιζούν στους ανθρώπους να μην πετάνε σκουπίδια στη θάλασσα

Όνομα: Νίκα

Figure D1. Rubric 4. Google Expeditions AR tool (Source: Field study)