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# Medical Education Escape Room Aligned with Flipped Classroom and Powered by Mobile Augmented Reality

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**Abstract:** Medical education escape rooms are emerging as a viable technological resource for pedagogy-first, learner-centric educational activities. This work presents the evaluation results of the first flipped classroom implementation in medical education, thus utilizing a mobile-driven augmented reality (AR) escape room. A total of 21 first-year medical students attended a flipped classroom educational activity that aimed to acclimate the students with the workflows of basic life support. Knowledge acquisition and user perceptions were evaluated. Knowledge acquisition was evaluated with an ad hoc relevant instrument at three timepoints: (a) baseline at recruitment, (b) preclass after students had prepared for the episode, and (c) after class. Learner perceptions about the activity and the AR escape room were recorded at the activity's end using a previously designed evaluation instrument. The results demonstrated sufficient knowledge acquisition only after completing the whole educational activity, while learners found the experience interesting, and the AR escape room challenging, thus reflecting an activity that was well formulated in structure and content. The challenges identified were the limited out of class collaboration capacity of the digital application and the highly gamified approach that at points counteracted the educational scope of the activity. Overall, these positive initial results demonstrate the potential of collaborative, escape based, activities for self-directed, learner-centric medical education.

**Keywords:** medical education; mixed methods; flipped classroom; escape room; augmented reality; mobile technologies



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## 1. Introduction

### 1.1. Educational Escape Rooms

Escape rooms are an emerging resource in the repertoire of experiential educators. Experiential learning methods are often used in patient sensitive workflows and safety training because they provide a safe setting where risks can be avoided. Therefore, it is not surprising that the escape room has been emphasized in the context of patient safety as a progression beyond basic simulation. Medical escape rooms can serve as a means of team building and an enjoyable method of providing educational content while considering the human issues involved, such as teamwork and communication [1,2].

The allure of escape rooms among contemporary learners is associated with a multitude of factors. This generation has been raised alongside technology and mass media,

with convenient access to personal computers and mobile phones [3]. This exposure is purported to have engendered a cohort that is distinguished by their proficiency in technology, their focus on objectives, and their self-assuredness in social situations. These learners are characterized as appreciating the opportunity to choose and experience a range of options, and they tend to like working together in teams. Furthermore, research has demonstrated that gamification effectively stimulates learners, enhances their involvement, and fosters social interaction within an educational setting. Consequently, it is not unexpected that this method of delivering education has gained significant popularity in the field of medical education in recent times [4]. Medical escape rooms offer an ideal platform to impart knowledge, skills, and behaviors in a gamified setting. The educational opportunities they offer prioritize collaborative learning, thus incorporating activities that necessitate teamwork and well-defined objectives while also providing an inherent mechanism for prompt feedback. Contemporary medical courses now prioritize human issues to a larger extent [2]. The conventional instructional approach restricts the ability to comprehensively understand the correlation between human factors and patient safety in clinical settings. Escape rooms can serve as a versatile method of medical simulation that encompasses all aspects of human dynamics. They offer a means to acquaint persons with healthcare procedures and replicate crucial learning experiences in a controlled environment while also offering an opportunity for debriefing.

Escape rooms are currently being utilized as a means of human factors simulation-based education (SBE) with great success. The process of SBE can be efficiently aligned with Kolb's experiential learning cycle, as it allows for active experimenting in a controlled environment before engaging in real-life events [5]. Debriefing and reflection are crucial for learning in Kolb's cycle, and the true significance of the escape room can be argued to lie solely in these components, which are also found in other forms of simulation-based education (SBE). Viewing escape rooms as a form of simulation-based education (SBE) is likely to also encompass the advantages of instructing human factors and other principles related to patient safety.

Delving further into the theoretical framework of educational value for escape rooms, self-determination theory emerges as a significant paradigm for elucidating the effectiveness of this game-based activity. Self-determination is a theory of motivation that posits the existence of a range of motivations to achieve, which can be impacted by external factors such as rewards or punishments, as well as internal reasons such as personal enjoyment [6]. The self-determination theory emphasizes the significance of satisfying psychosocial demands for competence, relatedness (sense of belonging), and autonomy. An effective escape room establishes attainable objectives for participants, promotes independence in decision making for learners, and incorporates efficient collaboration and guidance. According to certain gamification research, engaging in activities with peers can enhance motivation and facilitate subsequent learning [7]. A significant portion of the existing research in the escape room literature focuses on peer teambuilding activities and the use of facilitators who are slightly older or more experienced than the participants. The elimination of conventional hierarchies can serve as a motivating factor for learning within the escape room. The Flipped Classroom has emerged as a popular instructional approach in medical education, thus incorporating escape rooms as a learner-centric and self-directed activity.

### *1.2. Flipped Learning Collaborative Learning in Medical Education*

The Flipped Classroom methodology is a teaching approach where the practical aspects of education, such as activities and problem solving, are done in the classroom session. Conversely, the traditional practice of presenting information and educating is done outside class before the session begins [7,8]. The Flipped Classroom, when implemented appropriately, can be regarded as an active learning approach. It is an educational methodology that actively involves students in their own education process [9,10].

According to past research, most Flipped Classroom treatments follow a similar approach [11]. Initially, learners access an educational platform or system outside of the

classroom, where all material is stored. The purpose of this platform is to facilitate the learning process related to these materials. Furthermore, within the classroom setting, three primary methodologies are employed: engaging in problem debates, engaging in practical tasks or performances, and collaborating on group projects [11].

Based on these findings, the Flipped Classroom approach shows prospective benefits, particularly in secondary and university education. It is also found to be equally advantageous compared to other teaching methods utilized in primary school.

A frequently noted advantage of the flipped classroom is that students who utilize this approach are more inclined to cultivate advanced cognitive abilities with the guidance of their teacher and help from their peers. This is because the in-class time is mostly dedicated to cooperative learning and hands-on activities [12].

This modification could enable teachers to cultivate advanced cognitive abilities within the classroom, thereby drawing from Bloom's taxonomy [13]. Additionally, it would allow for students to independently, but with guidance, prepare themselves beforehand, thus focusing on the foundational cognitive skills of Bloom's taxonomy. Nevertheless, it is crucial to emphasize the additional advantages mentioned in the literature compared to traditional teaching methods, such as a customized approach to teaching and learning, enhanced class time management and organization, increased student accountability for their own learning process, and enhanced collaboration and learner-centric activities [14–17].

The efficacy of the Flipped Classroom methodology is contingent upon the autonomy and accountability of the learner, as participants are expected to be self-reliant in preparing for class. Perhaps because of this reason, the Flipped Classroom approach has been proven to be more effectively applied in higher education. University teachers strive to cultivate autonomy in their students' learning process, thus distinguishing them from school learners [18,19].

### *1.3. Pedagogies for Immersive Content*

There are two primary methods for incorporating immersive information into education: technocentric and educentric. Technocentric approaches utilize the inherent possibilities of technology as the foundation for creating instructional resources. Conversely, educentric models initiate the learning process as the foundation. Multiple studies comparing technology-centered methods with learner-driven approaches have consistently shown that technology-centered methods have yielded lower returns on capital investment and have not produced higher learning outcomes [20]. Educentric approaches prioritize pedagogical frameworks and explore how technology might be utilized to augment them. Pedagogy encompasses the dynamic interactions that occur among teachers, students, and the learning environment and task [21,22].

The significance of adhering to pedagogical theory rests in its capacity to enhance academic performance, foster social growth, and facilitate the development of technological proficiencies [23]. Technocentric approaches seek to utilize technology to provide an educational experience. Educentric approaches prioritize learning objectives and subsequently evaluate the most effective strategy for accomplishing it. For example, instead of asking how to shoehorn augmented reality for teaching basic clinical skills, it has proven far more effective to ask how to optimally teach basic clinical skills and from there explore whether augmented reality has significant positive impact in these endeavors.

### *1.4. Aim and Scope of This Work*

This work, to the authors' knowledge, is the first to explore the educational efficacy and perceptions of medical learners for a Flipped Classroom activity revolving around an educational AR escape room. As such, based on the literature citing the need for pedagogy-founded, multifaceted, technology-enhanced medical education [24], we aimed to evaluate the educational efficacy and the acceptance of a medical education escape room activity that was realized in a Flipped Classroom educational pedagogical context through a mobile-

based AR resource for undergraduate medical students. In that context, we explored with this study the following research questions:

RQ1: "Which processes in an AR based Flipped Classroom activity are effectively transferring knowledge to medical students?"

RQ2: "What are the perceptions, regarding acceptance, of undergraduate learners for an AR mobile-based escape rooms as a resource in their medical education?"

This paper is organized in the following sections: Section 1 is this introduction that presents related work, as well as contextualizes and presents the aims of this work. Section 2 is the Materials and Methods, including the description of the methodological affordances of our work. Section 3, the Results, presents the outcomes of our research, and finally, Section 4, the Discussion, comments on the results and presents the limitations and avenues of future work based on this research.

## 2. Materials and Methods

Our overall research design was a rather straightforward quantitative research methodology utilized in many educational evaluation studies. Specifically, we have utilized a sampling of opportunity using an ad hoc knowledge evaluation instrument and a previously developed acceptance instrument. We utilized these instruments to gather feedback from medical learners exposed to the main educational episode that was under evaluation.

### *2.1. The AR Escape Room*

Our augmented reality digital escape room seeks to teach the workflow of basic life support and trauma procedures. The AR escape room experience's narrative puts the player/learner in a cruise ship. A COVID-19 positive man falls unconscious in his suite and requires emergency medical attention. The unconscious man had suffered from a heart arrest episode. The user of the AR program must function as the on-site healthcare practitioner, thus assisting the sufferer to stabilize and preparing him to be transferred off-ship.

The resource is made up of a mobile AR app and a companion website. The companion website provides a series of uniformly formatted webpages. They feature a narrative description, an image that the mobile application may detect as an augmented reality image target, and a text area for entering escape experience progress codes. To reveal a number or letter code in the AR environment, the user must handle the relevant medical problem using their knowledge.

The companion website was created as a simple PHP page that waits for a response from the player/user and then either moves on to the next riddle or displays a notification/error message. The Vuforia AR developer kit was used to create the basic AR resource for mobile devices in the Unity game engine. The image targets were chosen and used for each of the seven problems that composed the entire escape experience. Each puzzle is followed by a brief description:

- Personal protection equipment (PPE) use: The user has to find and put in the correct order the PPE for protection against a COVID-19-positive patient.
- Airway obstruction puzzle: The user has to identify possible trauma evidence, and if there is none, they must move the patient, as well as check for and remove airway obstructions.
- Vital signs taking: The user has to apply oximeter and sphygmomanometer and understand the meaning of the received vital signs.
- Defibrillation process: The user has to identify the morphology of pulses for which defibrillation is warranted.
- Glasgow Coma Scale puzzle: The user has to understand how to interpret reactions and clinical signs according to the Glasgow Coma Scale.
- Preparation for evacuation: The user encounters the essential preparatory materials for transport to ambulance or evacuation.

- Meta puzzle: This puzzle is a pure riddle for the learners. It aims to train them to think out of the box by posing a problem that should be solved out of the AR application.
- Figures 1–5 demonstrate the hybrid (web and mobile AR) digital escape room.

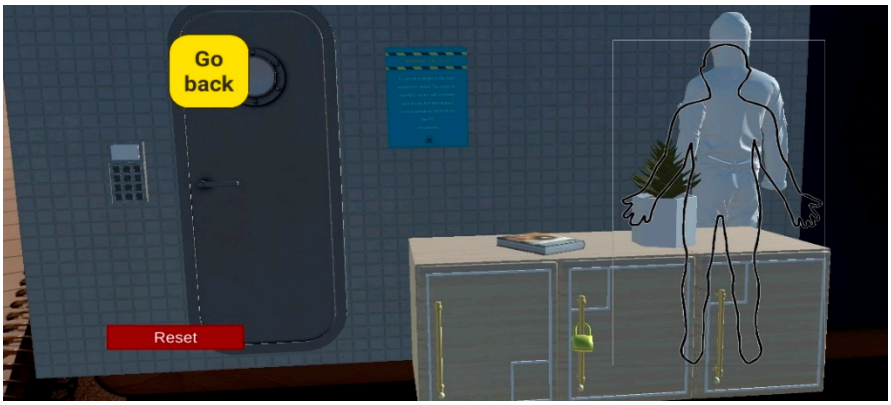


**Figure 1.** Screenshot of the AR mobile companion app of the escape room.

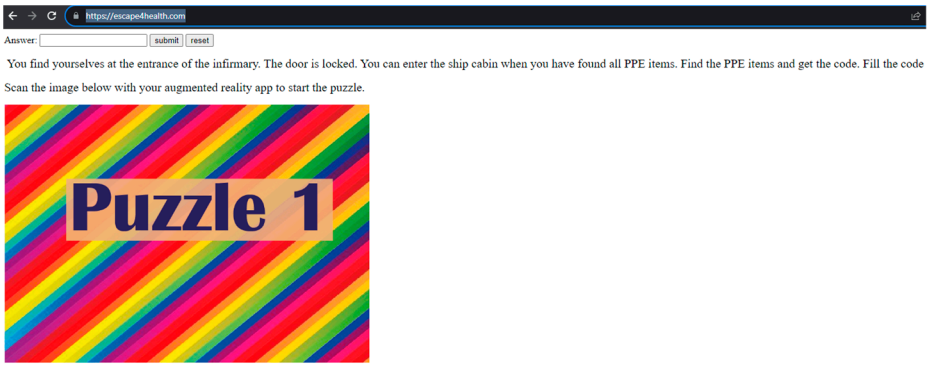


**Figure 2.** The simplified web-based escape room. A simple description accompanied with an AR target image and a field for code input.

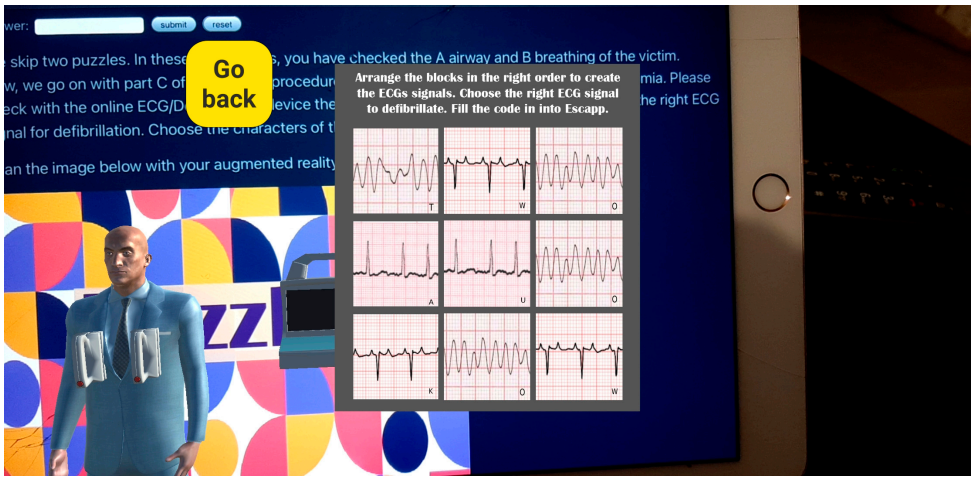


**Figure 3.** A sample puzzle for identifying ECG signals that can be defibrillated.

### *2.2. Participants*

The sample consisted of 21 students that were at their first or second year of medicine. Median age of the participants was 18 years, with the age standard deviation being 2.2 years. A total of 12 participants were female, 8 male, and 1 other. The recruitment process was conducted initially via email with an attachment of the study info sheet. This study was

approved by Aristotle University of Thessaloniki's Committee on Ethics and Research Ethics. Thus, those who agreed to participate received a detailed information form and provided informed consent prior to participation.

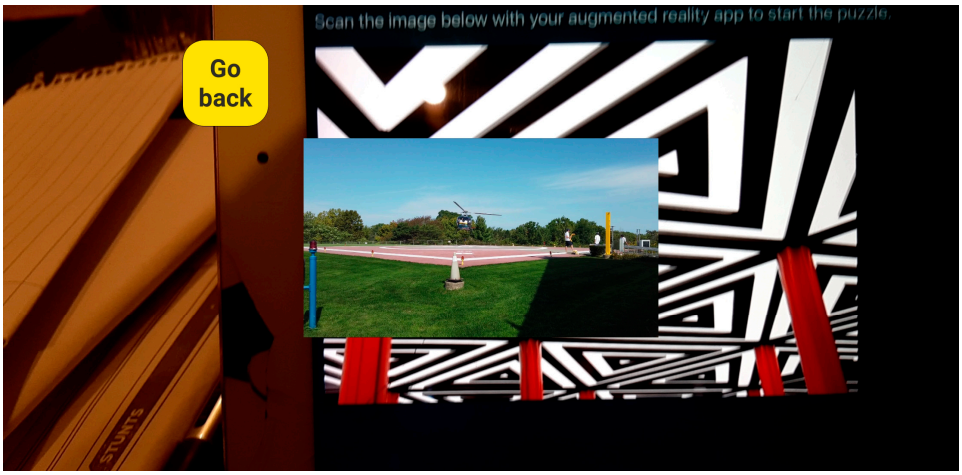


**Figure 4.** A Sample metanarrative puzzle for engaging the critical thinking of the learners.

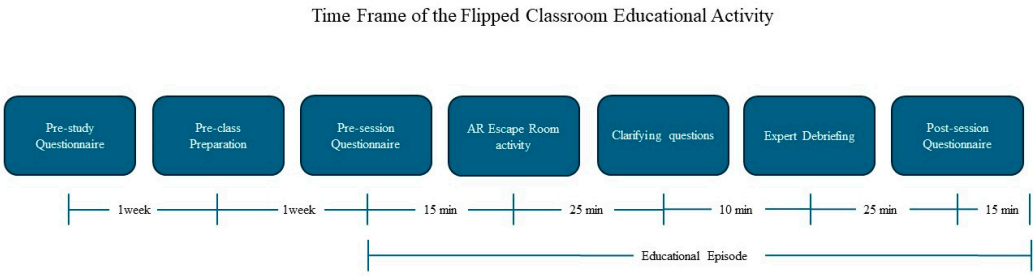


**Figure 5.** A graphical representation of the time frame of the flipped classroom educational activity.

### *2.3. Study Design and Procedure*

The Flipped Classroom educational activity that utilized the AR had as subject an introductory overview of the workflow of Basic Life Support (BLS). The processes that were distinguished in the scope of RQ1 are the well-documented flipped classroom stages. Specifically, they are the following:

- An introductory preclass presentation of the subject and the learning material: The learners were instructed to study resources about the workflow of BLS and be prepared to collaborate on a relevant in-class activity. At recruitment, the learners completed the baseline knowledge questionnaire.
- The flipped classroom episode: Then, they were instructed, in-class, to solve the AR escape room on their own as the initial activity, and they were prompted to ask any clarifying questions. The learners were asked to complete a preclass knowledge questionnaire before the activity.
- After that, the learners were debriefed on the correct workflow for BLS. and insights were offered based on facilitator class observations. After the activity, the learners completed the full postintervention battery of evaluation instruments, including the final knowledge questionnaire.
- The time frame of the flipped classroom educational activity is presented in Figure 5.

#### 2.3.1. Data Collection and Instruments

The session started with the introduction of the project, signing consent forms, and answering two questionnaires. To assess the skills on Basic Life Support (BLS), a self-report questionnaire was provided to students at three time points: before the training, during

the training, and after the completion of the training. The three different time points—pre-, during, and posttraining—were conducted to measure any potential changes in students' levels on BLS and their perspective on the Flipped Learning Approach. At the follow-up, all the students completed the assessment questionnaire on Basic Life Support and provided their opinions regarding the Flipped Learning.

#### 2.3.2. Perceived Usefulness Instrument

TELSON -WAVES is a self-report questionnaire previously developed and utilized for the TELSON (https://www.telson-project.eu/ accessed on 14 June 2024) and the WAVES (https://www.wavesnetwork.eu/ accessed on 14 June 2024) projects for evaluating perceptions of learners on problem-based and team-based learning strategies in the education of biomedical and life sciences. A modified version of it (using FC—Flipped Classroom—as the subject of the questions) was used and applied to this work. The modified instrument is presented below (Table 1):

**Table 1.** TELSON-WAVES Questionnaire.

| |
|---|
| The FC activity generated high quality discussion in the group. |
| The FC activity was exciting. |
| The FC activity generated high quality discussion in the group. |
| I was given all the resources I needed to get the most out of the FC session. |
| The FC session encouraged me to learn independently. |
| The FC session helped me develop my problem-solving skills. |
| The FC session allowed me to work as part of a team. |
| The FC session gave me the opportunity to apply the knowledge I already have. |
| While working on the case, I felt that I had to make decisions as a true professional. |
| While working on the case, I felt like I was the professional doing the analysis. |
| While working on the case, I was actively involved in gathering information (e.g., evidence, objective of analysis) needed to solve the case |
| While working on the case, I was actively engaged in revising my initial ideas about the necessary decisions with the new information I gained. |
| While working on the case, I actively engaged in thinking about what findings supported or contradicted my ideas and conclusions. |
| I felt the case was at an appropriate level of difficulty for my level of training. |
| The case questions helped to enhance the diagnostic assessment of the case. |
| After completing the case, I feel better prepared to act as a professional in a real incident analysis. |
| After completing the case, I feel better prepared to handle the positives and negatives in a real situation. |
| After the conclusion of the case, I feel better prepared to make an analysis of the situations that developed. |
| Overall, the case was a worthwhile learning experience. |

#### 2.3.3. Ad Hoc Knowledge Retention Instrument

It is common practice in knowledge assessment to draft topically relevant ad hoc knowledge questionnaires that are tailor-made to the material that is taught to the learners. Thus, to assess knowledge retention in each phase of the intervention (prestudy, preclass, after-class), we delivered a series of relevant knowledge questions to the participants. Also, to avoid «learning by testing», the questions were different in each stage of the knowledge assessment process. However, all the material of these questions was covered in both the preclass study material and the FC session with the AR mobile-based digital escape room, with each questionnaire being approximately equally challenging with the others.

This was ascertained by a topical expert who reviewed the questionnaires and verified their equivalence in terms of challenge level. The specific question for each stage of the educational episode is presented in Table 2.

**Table 2.** Ad hoc knowledge retention instrument.

| Prestudy Questions | Questions | Postsession Questions |
|---|---|---|
| What is the first action to a fallen person? | Which action is not part of the chain of survival? | What are the main stages of BLS? |
| What is the frequency of chest compressions in CPR? | What is the correct order in BLS? | After five cycles of CPR the patient remains pulseless, what do you do next? |
| What should approximately the compression depth during chest compressions be? | In automatic external defibrillator, what is the correct sequence of energies? | Identify the defibrillation rhythm in the figures below. |
| What is the correct ratio of chest compressions/infusions in CPR? | What are the main points of basic life support? | Select the correct sequence that describes the chain of survival. |
| What do you do immediately after delivering an automatic external defibrillator shock? | Which are the points of airway obstruction? | Select the correct sequence for wearing Personal protection equipment. |

## 3. Results

### *3.1. Perceived Usefulness Instrument*

Before presenting the collected data from the perceived usefulness instrument, we associated each of the questions with an aspect of the learner's perceptions. The associations created between each concept and each question are presented in Table 3.

**Table 3.** TELSON-WAVES questions linked with aspects of perceived usefulness.

| TELSON-WAVES Questionnaire | Aspects of Perceived Usefulness | Figure 5 Shorthand |
|---|---|---|
| The FC activity was exciting. | excitement/engagement | exciting |
| The FC activity generated high quality discussion in the group. | quality discussion team | quality discussion team |
| I was given all the resources I needed to get the most out of the FC session. | adequateness of resources | adequateness of resources |
| The FC session encouraged me to learn independently. | independent study | independent study |
| The FC session helped me develop my problem-solving skills. | problem solving | problem solving |
| The FC session allowed me to work as part of a team. | teamwork | teamwork |
| The FC session gave me the opportunity to apply the knowledge I already have. | knowledge application | apply knowledge |
| While working on the case, I felt that I had to make decisions as a true professional. | real decisions making | real decisions |
| While working on the case, I felt like I was the professional doing the analysis. | verisimilitude to profession I | verisimilitude to profession |
| While working on the case, I was actively involved in gathering information (e.g., evidence, objective of analysis) needed to solve the case | active information gathering | active information gathering |

**Table 3.** *Cont.*

| TELSON-WAVES Questionnaire | Aspects of Perceived Usefulness | Figure 5 Shorthand |
|---|---|---|
| While working on the case, I was actively engaged in revising my initial ideas about the necessary decisions with the new information I gained. | reflective thinking I | reflective thinking I |
| While working on the case, I actively engaged in thinking about what findings supported or contradicted my ideas and conclusions. | reflective thinking II | reflective thinking II |
| I felt the case was at an appropriate level of difficulty for my level of training. | challenge level | challenge level |
| The case questions helped to enhance the diagnostic assessment of the case. | well-formulated case | well-formulated case |
| After completing the case, I feel better prepared to act as a professional in a real incident analysis. | verisimilitude to profession II | verisimilitude to profession II |
| After completing the case, I feel better prepared to handle the positives and negatives in a real situation. | resilience building | resilience building |
| After the conclusion of the case, I feel better prepared to make an analysis of the situations that developed. | positive affect | positive affect |
| Overall, the case was a worthwhile learning experience. | overall opinion | overall |

Given these links, Figure 6 presents, at a glance, the participant's perceptions about their experience with the AR mobile-based digital escape room in a Flipped Classroom activity.

### *3.2. Ad Hoc Knowledge Retention Instrument*

The differences between the means of our three within-subjects levels of knowledge retention (number of questions answered correctly) are presented in Table 4:

**Table 4.** Knowledge retention results at assessed flipped classroom time points.

| Successfully Answered Questions (Out of a Total of 5) | | | |
|---|---|---|---|
| | **Mean** | **SD** | **N** |
| Prestudy (Baseline) | 2.62 | 1.32 | 21 |
| Preclass (Self-study) | 2.76 | 0.95 | 21 |
| Postclass (After FC Activity) | 4.14 | 0.79 | 21 |

The baseline and the self-study knowledge retention results do not present any notable difference, while the postclass results present a significant improvement in questions answered correctly. A pairwise comparison, specifically a Wilcoxon signed rank test, revealed that students' scores were significantly higher after the training session, where $z = -3.26$ and $p = 0.001$, with a medium to large effect size. This analysis indicated that the degree of change of knowledge between presession (baseline data) and post-FC session was statistically significant. The analyses between the two time periods indicated significant advantages in performance after time spent in class compared to the preclass group and baseline group, as shown in Table 4.

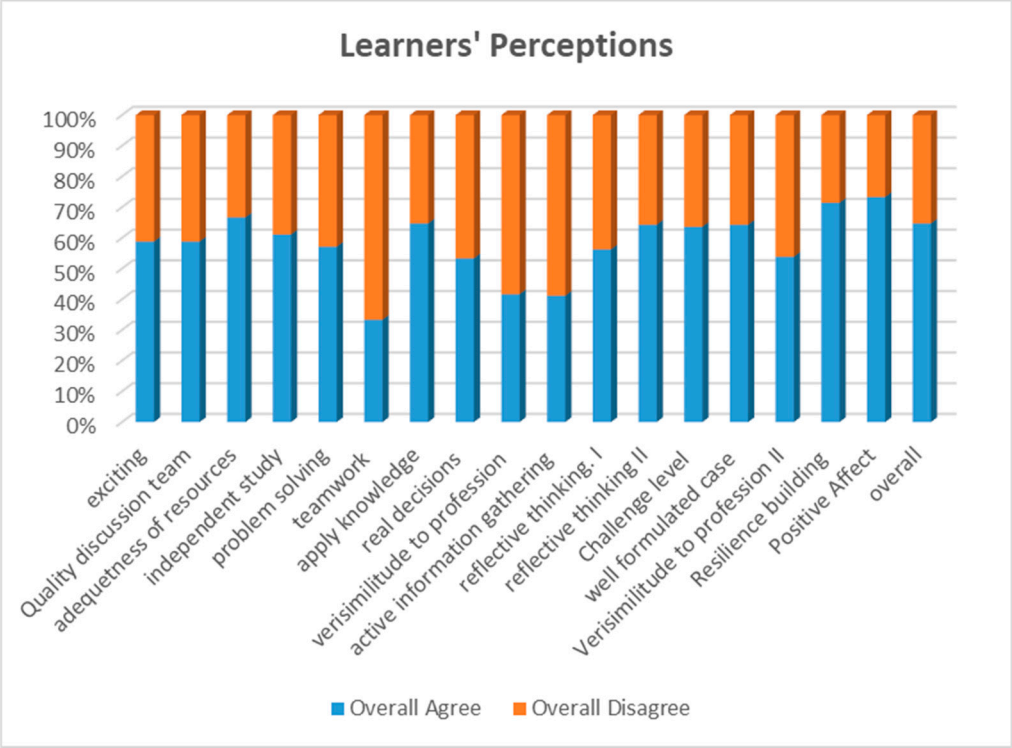


**Figure 6.** Learner perceptions regarding usefulness of the AR medical education escape room.

## 4. Discussion

### *4.1. Primary Results*

There have been several studies about physical and digital escape rooms in education (cf. [1]). There, the still prevalent methodological approach is, like in any novel technological enabler, to evaluate the efficacy and perceptions of the escape room itself as a resource. The educational use of the escape room modality has greatly advanced. Methodological studies have provided experiential insights [25], but, more importantly, they have discovered sequential linear pathways, each of which must be cleared before proceeding to the next one. This configuration enables the allocation of each pathway to a distinct didactic unit, chapter, issue, or learning purpose [26]. Similar emphasis on instructional rigor has been observed in other domains, such as STEM with learning objectives being precise and quantifiable, as well as accurately representative of the knowledge, abilities, and attitudes that students are expected to gain from the activity. This was, in fact, also our approach for our AR-powered medical escape room. Each stage of the escape room was a complex activity conducted in the AR mobile application, which was related to a very specific learning objective. Several of these puzzle activities required multiple steps to solve; however, each of them revolved around very specific learning objectives. Themes and narratives should captivate and inspire students while remaining pertinent to the subject matter and cultivating a spirit of curiosity and discovery. Similarly, in our escape room activity, we framed the educational puzzles in an engaging narrative—that of a COVID-19 quarantined cruise ship in which an acute incidents required immediate medical care. That way, we avoided the trivialities of a dry medical case recitation. Instead, we presented the learners with a narrative theme that engaged them akin to an adventure thriller, thus maintaining their engagement across all activities. Ultimately, the literature highlights the need to assess learning outcomes. It is important to assess digital escape rooms in order to measure their efficacy in meeting the learning goals. This can entail the utilization of evaluations, quizzes, or surveys that evaluate student knowledge, skills, and attitudes prior to and following the activity. The evaluation should be used to pinpoint areas for enhancement and to fine-tune the concept and execution of forthcoming digital escape

rooms [27]. Recently, a guide on creating and running escape rooms for medical education denotes the transition from novelty to curricular acceptance [28]. Adhering to similar principles, we applied a rigorous evaluation regimen, with multiple time point evaluations for knowledge retention, as well as a rather extensive questionnaire suite for a multifaceted evaluation of the user's acceptance of the educational activity.

In that context, the work presented here is the first that (a) follows an educentric approach instead of a technocentric one, thereby evaluating a full educational activity instead of its resource, and (b) implemented a Flipped Classroom educational activity that is using an AR medical educational escape room as its core educational resource.

Summarizing these results, we can outline the following specific points:

- The overall educational experience was positively received and engaged the students.
- The AR escape room provided adequate content and level of challenge, as well as presented a well formulated case.
- The AR escape room encouraged reflective thinking and helped the learners build resilience in their problem-solving skills.
- The AR escape room in the Flipped Classroom format provided a measurable educational effect only as a whole episode. Self-study alone with the digital resource was not adequate for knowledge transfer and retention.
- The weakest points of the AR escape room were on teamwork and verisimilitude to a realistic situation. This was due to the format of the delivered FC episode, where each participant was individually engaged with the digital resource. Also, this is due to the highly gamified approach of the scenario that detracted from clinical realism. While this was a conscious choice (this was an introductory educational episode before actual clinical practice), it would be interesting to explore shifts in perceptions with a more complex scenario.
- Overall, the flipped classroom activity, utilizing an AR escape room, was deemed a positive educational activity, and feedback was pointing toward the need for further inclusion in curricular activities.

### *4.2. Limitations and Future Work*

This pilot study aimed to expand this research following an educentric, pedagogy-relevant methodology in order to explore the efficacy and acceptance of a Flipped Classroom activity that revolved around a digital, mobile-based AR escape room. It has provided some encouraging results for the educational efficacy and the acceptance of this activity revolving around a digital, Mobile Augmented Reality (MAR) escape room. It is an educentric study, thus putting pedagogical prudence before technical novelty. However, it can be construed only as the beginning in the exploration in this specific educational use case.

Specifically, this was a pilot study, with an adequate but small sample size. Its results need to be verified to a much larger cohort in order to explore the pedagogical nuances of integrating such a technological resource in specific educational activities.

A second limitation of this study was the reduced collaborative potential of the AR escape room. The digital application was not natively networked. As such, it lacked the capacity to support transparent collaboration between users requiring synchronous, physical presence in order to achieve this collaborative setting. An enhanced, fully networked application would offer a far greater capacity for exploring collaborative learning potential, even in distance learning scenarios. Furthermore, the platform duality (website and mobile AR app) will need to be critically evaluated against a more straightforward (e.g., web-based only) approach in order to ascertain the appropriate technological combination for digital escape room pedagogies in Flipped Classrooms.

Thirdly, this study piloted the use of a digital escape room in a standardized Flipped Classroom setup. The escape modality is uniquely fit for a Flipped Classroom approach. Putting together a newly encountered set of challenges, with self-motivated preparation and limited facilitator support can enhance learner autonomy, confidence, and openness in collaboration. Additionally, debriefing after the fact, taken right out of the Flipped

Classroom manual, is a very efficient way to engage with the learners right at the time when they are most engaged with the educational topic. Expanding research in other, collaborative, learner-centric activities and deployment modalities (e.g., headset-mounted AR) would provide very useful insights on what exactly are the educationally impactful components of the escape room activity moving toward an "escape room pedagogy".

Whenever a new technology emerges, it is likely to be accepted as an improvement and an ab initio factor of positive change in the current practices. Prudent scientific methodology avoids such preconceptions. It is in that concept that this study was conducted. The overall aim of it was not to evaluate digital escape rooms in medical teaching but to evaluate the overall educational activity of the Flipped Classroom when an MAR escape room is the technology enabler. In that context, we have indeed demonstrated that a digital escape room can be a valid technological enabler in a Flipped Classroom setting. Furter study is required to ascertain the impact of the technology itself against the overall effect of the educational activity.

This hybrid medical education escape room consisting of a mobile AR app and a website for inputting the puzzle responses is really a first iteration experimental setup for a proof of educational application. While it would be possible to go directly for a fully functional medical escape room with an AR headset (e.g., a Hololens-deployed application), this would be an unnecessary resource sink before ensuring that a basic setup produces sound educational outcomes. Thus, this study, with a basic but efficient AR medical escape room setup, aims to be a milestone evidence base for opening up the opportunities of upscaling the technological intensity of such educational activities, e.g., through a fully immersive, headset-based medical escape room.

Even though the use of escape rooms has grown in popularity, its long-term viability is still uncertain. There is a multitude of evidence of popular 'disruptors' in medical education, the lifespan of which varies widely. While innovation and disruption should be at the forefront of the immersive education practitioner, prudence suggests caution, thus keeping in mind that significant lessons can be gleaned towards the long-term viability of any new initiative. In that context, this work is one of the first in such an endeavor, thus providing positive results on the educational value of escape-based collaborative learning activities.

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