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Digital Estuaries: Exploring the Pedagogical Benefits of Virtual Reality Media in Geography and Spatial Analysis

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ABSTRACT

Learning eco-spatial concepts and estuary conservation concepts in Geography is often constrained by irrelevant learning media and limited field trips. As marine conservation is critical to addressing damage to coastal and marine ecosystems, there is an urgent need for innovative learning media that can bridge this gap. To address this, our research focuses on the development and evaluation of Virtual Reality Estuary learning media. This interactive tool provides a realistic virtual representation of the real world through a 360° panorama. It is designed to offer students an immersive experience, enhancing their understanding of the topics of eco-spatial concept and estuary conservation. We used a Research and Development (R&D) approach using the Successive Approximations Model research method. This research uses primary and secondary data. Primary data is based on field data and product validation tests. Secondary data was obtained from literacy data from accredited journals. Data needs analysis using a questionnaire submitted to students. The analysis shows that the use of virtual reality media is needed in estuary learning. This research resulted in the development of Virtual Reality Estuary media. Virtual Reality Estuary media development products have gone through the media product validation test stage and material validation test with declared valid and feasible to use. So that students can do digital exploration through Virtual Reality Estuary in geography learning.

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1. Introduction

Natural conditions can be useful for learning about geospheric phenomena. Spatial and ecological interaction patterns unite geospheric phenomena, creating a diversity of complex ecosystems (Roell et al., 2021). One of these interaction patterns can occur in estuary environments (Hollenbeck et al., 2019). Estuaries often face serious environmental pressures due to human and natural activities (Lacerda et al., 2019). Human activities that can affect ecosystem damage include mangrove logging in watersheds, and coastal development (Romañach et al., 2018). Increasing water temperatures, rising sea levels, and changing weather patterns can affect the survival of estuary ecosystems (Scalpone et al., 2020). Ecologically, estuaries play an important role in maintaining the balance of coastal estuary ecosystems (Wu et al., 2018). Learning estuary materials should include an understanding of how human activities can damage estuary ecosystems and measures to protect them (Choi et al., 2021). Therefore, the study of Geography is important to understand the ecological conditions in coastal estuaries.

Estuary studies offer students a profound understanding of coastal area conservation. Estuaries encompass diverse ecosystem zones (Rocha et al., 2021). These estuary zones include the ecotone, mangrove, intertidal, and subtidal regions (Snyder et al., 2022).Geological activity, hydro-morphology, weather patterns, and climate dynamics contribute to the formation of estuary zones (Yilmaiz et al., 2021). Estuaries hold significant importance in Geography education, particularly as a tool for analyzing geospheric phenomena on the earth's surface (Elliott et al., 2016).

In this context, students often encounter challenges in grasping the concept of estuaries within the context of geospheric studies in Geography (Detyna & Kadiri, 2020). Low absorption in understanding the concept of estuary by students makes learning outcomes low. This is in line with the statement of Ridwan et al (Ridwana et al., 2022) that low learning outcomes are caused by a lack of student interest in learning and the use of less interesting and relevant learning media. Then Syawaluddin et al (Syawaluddin et al., 2020) said that low student learning outcomes are caused by many factors, one of which is the lack of utilization of interesting learning media. This is in line with research conducted by Dahlia et al (Dahlia et al., 2022) which states that the media is said to be effective if it can arouse students' interest and motivation to actively follow and listen,

listen to learning. Estuaries in Geography education serve as a comprehensive learning resource (Wang et al., 2020). Concepts, principles, and methodologies in Geography education have seamlessly integrated with studying estuaries. Estuaries function as natural laboratories that facilitate students' comprehension of geospheric phenomena and support experiential learning activities in Geography (Gosal et al., 2021). Thus, students can apply contextual knowledge during field trips to estuary natural laboratories.

Several challenges hinder the application of estuary knowledge during field trips, with one significant obstacle being the limited accessibility of study locations from schools. Additionally, Geography educators often employ less interactive learning materials, making field trip-based learning a demanding task (Chatziralli et al., 2021). To improve students' ability to analyze field phenomena such as estuaries directly, they must engage in exploratory experiences (Hamilton et al., 2021). This is in accordance with the results of research conducted by Lahay & Mohamad (Lahay & Mohamad, 2020) that conceptually carrying out a study tour or field trip at several locations as a geography laboratory will facilitate students in learning the study of geographic phenomena contextually. Furthermore, teachers need to play a pivotal role in introducing innovative contextual learning tools within Geography education (Putra et al., 2023).

The landscape of Geography education has undergone substantial transformations in the aftermath of the COVID-19 pandemic (Putra et al., 2022). According to research by Putra et al., (Putra et al., 2021) contextual learning Geography shows that the lack of relevant media and materials is an obstacle to learning, the innovation is the use of Augmented Reality media on the completeness of student problem solving. So that alternative solutions to overcome contextual learning problems related to estuaries can be through the use of virtual reality media. Conventional teaching methods have evolved into technology-driven pedagogy (Ironsi, 2022). Consequently, educators must proactively seek solutions to facilitate contextual field-based Geography knowledge acquisition by harnessing virtual reality technology.

The utilization of virtual reality technology stands as a cornerstone concept in the development of innovative educational media for exploring estuaries. VR Estuary, as an educational solution, facilitates the presentation of natural phenomena within a virtual environment (Fahmi et al., 2022), offering students an immersive learning experience (Kamińska et al., 2019). Because VR allows users to feel the real environment even though it is virtual (Pleyers & Poncin, 2020).This is related to the features contained in VR that support the learning process (Makransky & Petersen, 2019). The integration of Virtual Reality Estuary into Geography education serves as a viable substitute for traditional contextual learning approaches without compromising the depth and breadth of the educational content (Bursztyn, 2020).

As a pioneering tool in Geography education, the Virtual Reality Estuary offers an immersive pedagogical approach, allowing students to engage deeply with their environmental context (Stojšić et al., 2017). Monita & Ikhsan (Monita & Ikhsan, 2020) embarked on analogous research concerning the development of virtual reality as a medium for science education. However, their exploration was predominantly constrained to science-centric educational content. Concurrently, Arkadiantika et al (Arkadiantika et al., 2020) innovated virtual-based instructional media focusing on introducing termination and splicing of fiber optic materials to students. So that the Virtual Reality Estuary media can realize field trip learning through Virtual Reality media

The advancement of the Virtual Reality Estuary (VRE) platform constitutes a monumental leap in Geography education, positioning itself as an indispensable instrument for virtual fieldwork exploration. Traditional pedagogical paradigms, which underscore the primacy of field-based engagements, often grapple with logistical impediments due to the geographical expanse between educational institutions and pertinent study locales (Azhari & Fajri, 2022). Furthermore, direct interactions with real-world terrains can inadvertently subject students to a spectrum of complexities, ranging from logistical hurdles to potential hazards a myriad of challenges judiciously circumvented in a virtual pedagogical milieu (Hwang & Chien, 2022). Such digital ecosystems, underscored by their innate flexibility and interactive prowess, foster a dynamic, learner-centric ambiance, fortifying engagement and pedagogical adaptability (Wang et al., 2022) . Given these attributes, the VRE medium crystallizes as an instrumental conduit, facilitating students' immersive engagements with virtual ecological terrains.

VR-based field trip media can be customized to meet students' specific learning needs, increasing their engagement and understanding (Petersen et al., 2020). To advance Geography education, it becomes imperative to develop a 360° Virtual Reality Estuary solution with comprehensive content, effectively encapsulating the intricate concepts related to estuaries (Han, 2020). Students are afforded the opportunity to embark on a virtual journey, exploring the estuary environment through Virtual Reality Estuary. This virtual field trip is meticulously designed to provide users with 360° panoramic images, enabling them to experience the estuary from all angles (Harrington et al., 2021).

The development of Virtual Reality (VR) Estuary emerges as a transformative solution addressing the challenges encountered in contextual Geography learning, with the potential to heighten students' environmental awareness significantly. Within this context, students engage with and gain insights into estuary concepts while analyzing various phenomena rooted in the ecosystem's distinctive characteristics (Bos et al., 2022). Notwithstanding the promise of Virtual Reality Estuary, there exists a research gap in comprehending its full potential for effectively conveying the intricacies of the estuary environment. The literature acknowledges the ability of Virtual Reality Estuary media to virtually represent the estuary ecosystem's characteristics (Calil et al., 2021) however, further exploration is warranted to ascertain the extent of its impact on students' critical thinking abilities through virtual observations (Kamil et al., 2020). As this area is delved into more deeply, it becomes evident that implementing Virtual Reality Estuary learning media holds the potential to facilitate meaningful student interactions with their surrounding environment, marking a significant advancement in Geography education. The development of estuary virtual reality aims to help students understand the concept of estuary and spatial geography analysis well.

2. Methods

This study constitutes a research endeavor categorized under the Research and Development (R&D) framework. The research employs the Successive Approximations Model (SAM) as its developmental framework. The SAM, introduced by Czerkawski & Berti (Czerkawski & Berti, 2021) is recognized for its straightforward procedural approach tailored to the demands of development projects. The SAM 1 model, as outlined by Allen and Sites (Allen & Sites, 2012), encompasses three essential phases: Evaluation, Design, and Development. The flow of media development is described in Figure 1 as follows:

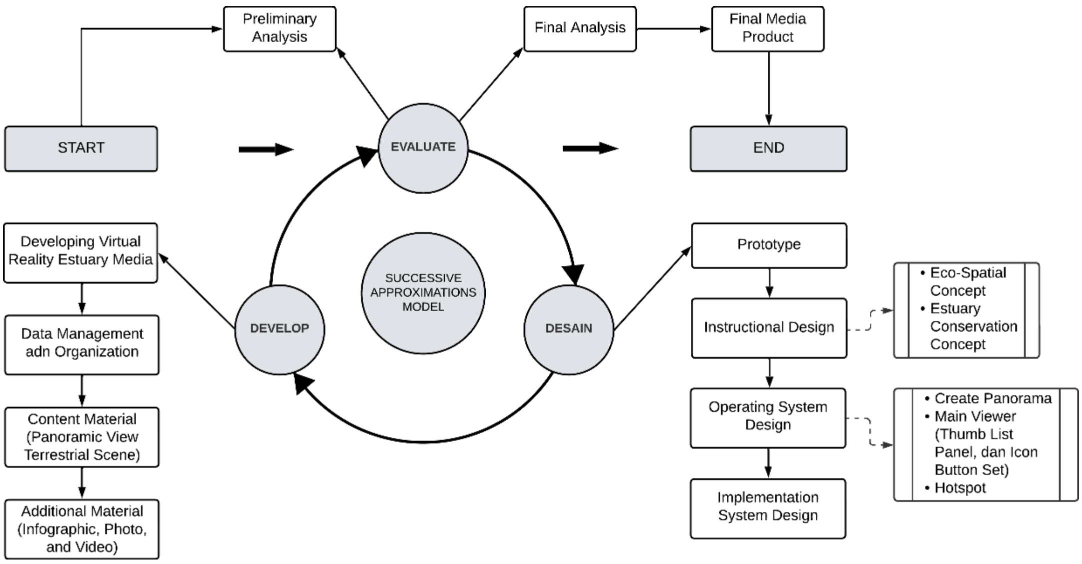


Figure 1. Development Flow Chart
Source: Allen & Sites, 2012, modified by the researcher, 2023

Based on Figure 1, the following is an explanation of the development procedure in this study.

2.1. Evaluate Phase

The SAM development stage in this study begins and ends with the evaluate stage. The initial Evaluate stage includes activities to analyze student needs, curriculum, materials, and media analysis. Data on needs analysis was obtained through observations, interviews and questionnaires. Feedback from these observations, interviews and questionnaires, combined with the literature review, informed the next stage of development. Then the final Evaluate stage is a product finalization activity based on the results of formative evaluation at the end of each stage and summative evaluation at the final stage of development. The results of this crucial evaluation phase determine the quality of the final product.

2.2. Design Phase

The next stage of development is the design stage. In the design stage, prototypes are made that refer to instructional design and operating system design. instructional design is based on the needs of learning materials and media. While operating system design is based on the visualization needs of learning media designed in reference to instructional design. Then the implementation system design is carried out to realize the instructional design and operating system.

2.3. Development Phase

In the next stage of development, the conceptualized design transitions into a real prototype, supported by a careful product validation process. The product is carried out media validation and material validation. The product validation process is carried out to obtain feedback on the results of product development. The results of media and material validation were used to make improvements to produce the final product at the final evaluation stage. A nuanced evaluation of media efficacy was conducted by describing data statements that summarized the results of the product validation procedure. This analytical effort is based on the product validity test, which has been carefully examined by virtual reality technology experts. In addition, it should be noted that this validation was supported by leading professional academics in the field of geography from the State University of Malang.

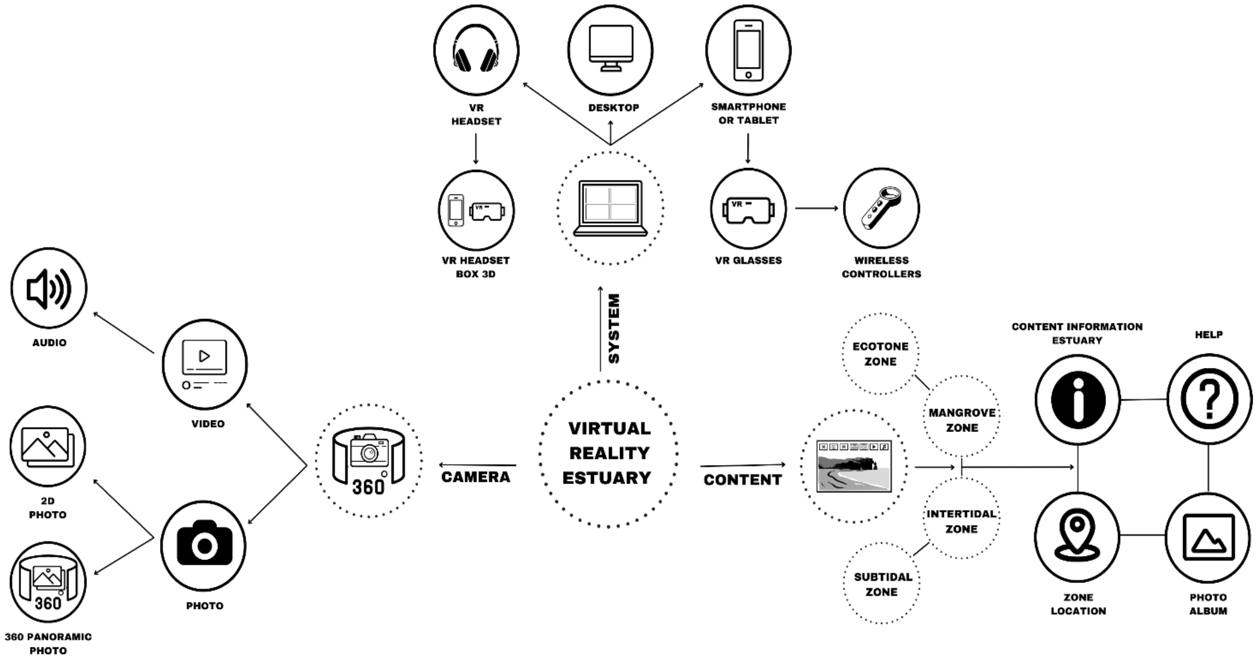


Figure 2. Framework Development Design

Frameworking is done before the product development stage to produce a product design. The product design is a series of main components that are integrated with each other and form the Estuary Virtual Reality product prototype. The product was developed using the 3D Vista Virtual Tour application. The Virtual Reality Estuary product development framework refers to three main components: content, camera, and system as shown in Figure 2.

Content on Virtual Reality Estuary media presents material through the information estuary content menu, zone location, photo album, and help. The material content was collected in the Clungup Mangrove Conservation (CMC) Tiga Warna area. The camera component in the development of Virtual Reality Estuary media refers to the format of the content to be presented. The formats used in this media development are 2D photo format, 360° panoramic photo and video format with audio. Then the system component is an option related to the device to access Estuary Virtual Reality media. To access this media, users can use desktops, as well as smartphones or tablets via VR glasses and wireless controller. Users can access this media directly using a VR Headset equipped with a 3D VR Headset Box.

3. Results and Discussion

This research resulted in the development of Virtual Reality Estuary media. The development of this research product is based on student needs analysis, curriculum, material, and media analysis. Virtual Reality Estuary media development products have gone through the media product validation test stage and material validation test and are declared valid and suitable for use. Virtual Reality Estuary media helps students in conducting virtual field trips. This media is designed to present eco-spatial concept and estuary conservation material. Virtual Reality Estuary media helps students understand the concepts and characteristics of estuaries.

Figure 3. Main View of Virtual Reality Estuary

The Virtual Reality Estuary platform provides an advanced visualization interface, integrating eco-spatial concepts and estuary conservation principles into an immersive 360° panoramic view. This media can be accessed both online through the web platform and offline through mobile or desktop devices. Figure 3 describes the main navigation interface, displaying the main menu of the Virtual Reality Estuary display. This visualization is realized by utilizing the create 360° panorama feature which allows combining panoramic photos and providing information into Virtual Reality Estuary media. To facilitate navigation in virtual media exploration activities, it provides a hotspot feature to move to the next location. The hotspot feature comes with a selection of icons to simplify operation and movement of the panorama.

Through the use of skin element settings, Virtual Reality Estuary media provides various menus and features that can be accessed by users. The menu includes information, estuary sites, photo albums, and a help menu as a user guide. In addition, Virtual Reality Estuary media also provides various features to facilitate exploration activities through thumbnail list panoramas and button sets. Thumbnail list panorama serves as a tool to facilitate users to go to the desired location. Meanwhile, the button set offers many variations in supporting media usage such as audio on/off button, fullscreen, and VR glasses access button. Virtual Reality Estuary media display design was developed to facilitate the use of Virtual Reality Estuary media in the learning process.

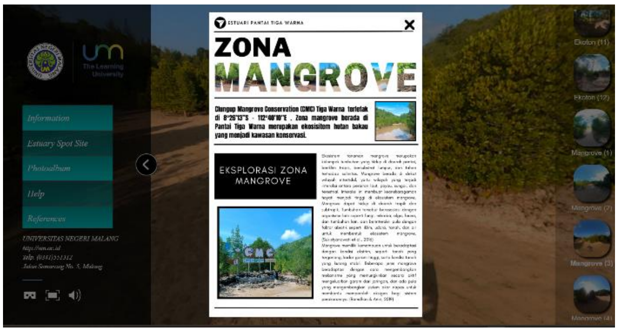


Figure 4. Information Display on Estuary Virtual Reality in Infographics

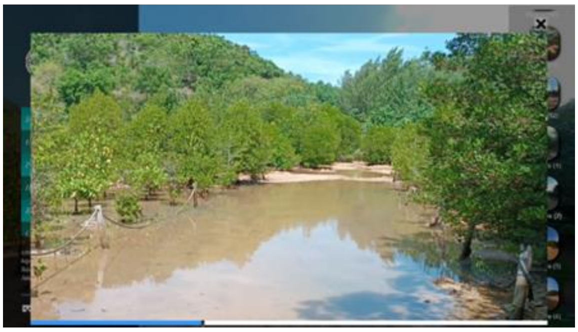


Figure 5. Video Information Display in Estuary Virtual Reality

Material information in Virtual Reality Estuary is presented using hotspots icons in infographic and video formats. In Figure 4 is a display of information in infographics on Virtual Reality Estuary media. In addition, Figure 5 is a video display on the virtual reality Estuary media which contains the environmental conditions of each estuary zone. The wide variety of utilization of the hotspots feature can facilitate users in information literacy and access to material content. The design of information and video displays in virtual reality (VR) media is a key aspect of creating an immersive experience for users.

Table 1. Estuary Virtual Reality Framework Development

Main Features	Main System	Material Content
Content	Spot Site Area	Tiga Warna Beach Estuary Zone (Ecotone Zone, Mangrove Zone, Intertidal Zone, Subtidal Zone)
	Content	Information related to the Tiga Warna CMC Estuary includes the Ecotone Zone, Mangrove Zone, Intertidal Zone, and Subtidal Zone.
System	Desktop	Verification and exploration process in the Tiga Warna CMC Estuary area
	Head Mounted Display (HMD)	
	Smartphone atau Tablet	
Camera	Photo	Describe evidence of the Tiga Warna Beach Estuary Ecosystem
	Video	

Panorama in Virtual Reality Estuary packing the formation of the estuary zone of Tiga Warna Beach. Thus, the panoramic spots of Virtual Reality Estuary are the ecotone zone, mangrove zone, intertidal zone, and subtidal zone. The panorama spot refers to the design of the Virtual Reality Estuary architecture system, which consists of (1) Content (Visualization of content), (2) System (Presentation and access in Virtual Reality Estuary), (3) Camera (Virtual Reality Estuary media input). Development of features to facilitate students in accessing material content in the form of audio-visual (photos and videos). The design of each feature has a function to support learning activities. The Virtual Reality Estuary generally developed a design of main features, central systems, and material content, as shown in Table 1.

Virtual Reality Estuary features made to support Geography learning activities efficiently and effectively. Each feature has learning activities that can improve cognitive abilities in students (Albus et al., 2021). The main features of the central system in content emphasize information literacy activities and content search about the Tiga Warna Beach Estuary. Information literacy in the features focuses on verification and exploration learning activities on the Tiga Warna Beach estuary. Students can access all desktop, smartphone, and HMD features on the Virtual Reality Estuary system. System features integrated with camera features as supporting input media in photos and videos. Then, features are emphasized in learning activities by explaining and showing evidence in the Tiga Warna Beach estuary. The discovery of exploration results can help students reconstruct the Tiga Warna Beach estuary concept.

Table 2. Virtual Reality Content Estuary Panorama of Three-Color Beach Estuary

Spot	Location	Geography Characteristics
Ecotone Zone	8°25’56”S - 112°40’24”E	Vegetation, Fauna, Landscape, Land Cover, Morpho-arrangement
Mangrove Zone	8°26’13’’S - 112°40’10’’E	Vegetation, Fauna, Landscape, Land Cover, Conservation, Hydrological Characteristics, Morpho-arrangement
Intertidal Zone	8°26’21’’S - 112°40’39’’E	Vegetation, Fauna, Landscape, Land Cover, Conservation, Hydrological Characteristics, Morpho-arrangement
Subtidal Zone	8°26’25’’S - 112°40’42’’E	Vegetation, Fauna, Landscape, Land Cover, Conservation, Hydrological Characteristics, Morpho-arrangement

Figure 6. Spotsite Plotting Virtual Reality Estuary Panorama of Three Colors Beach Estuary

Figure 6 Represents the content collection points of each estuary zone. Virtual Reality Estuary provides an overview of the Tiga Warna Beach estuary through the content contained in each feature. This media is designed for learning needs related to understanding the concept of eco-spatial concept and estuary conservation. The presentation of estuary content in this media conveys estuary concepts, estuary characteristics, and ecological interactions in estuaries. Virtual reality technology can help students understand estuaries more easily and interactively. Virtual reality technology can also simulate the visualization of phenomena in the environment (Baceviciute et al., 2021), especially in this study in the estuarine zone of Tiga Warna Beach. The media content is displayed with an integration between panoramas in each estuary zone. The panoramic view shows the different characteristics of the estuarine zone area due to ecological interactions. So VR technology can help students expand their understanding of complex Geography information related to estuaries. Simulation of the virtual environment of the estuary ecosystem on the Virtual Reality Estuary media refers to the division of the estuary zone, which is presented in the spotsite as follows.

Virtual Reality Estuary media development in the first exploration presented the ecotone zone (table 2). The material on ecotone zones is presented in the form of videos and photos. Users can obtain information related to the ecotone zone through the hotspots feature on the Virtual Reality Estuary media. Figures 7 are panoramic views presented to build Virtual Reality Estuary media in the ecotone zone. The ecotone zone is part of the Tiga Warna Beach estuary exploration area as a complex Geography learning study. Ecotone zone complexity has diverse ecosystems (Ding et al., 2020).

(a) Panoramic Photo of Ecotone Zone

(b) Panoramic Photo of the Border between Ecotone Zone and Mangrove Zone

Figure 7 Spotsite 1: Ecotone Zone

Ecotone zones are transitional areas between different ecosystems, namely terrestrial and coastal ecosystems (Schlacher et al., 2020). Virtual Reality Estuary media can interact and explore various ecosystems in the ecotone transition zone. Students can develop a more holistic view of the ecological system of the ecotone zone through exploration activities. So that students' understanding of the ecotone zone contributes to environmental sustainability.

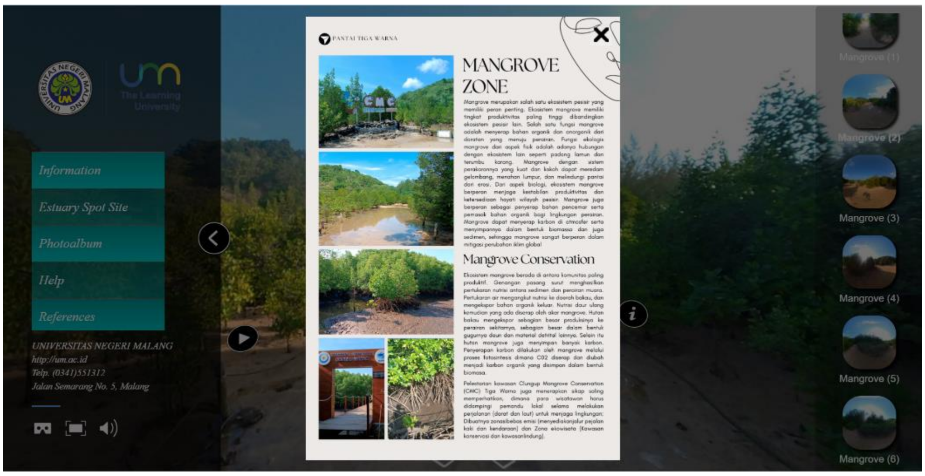
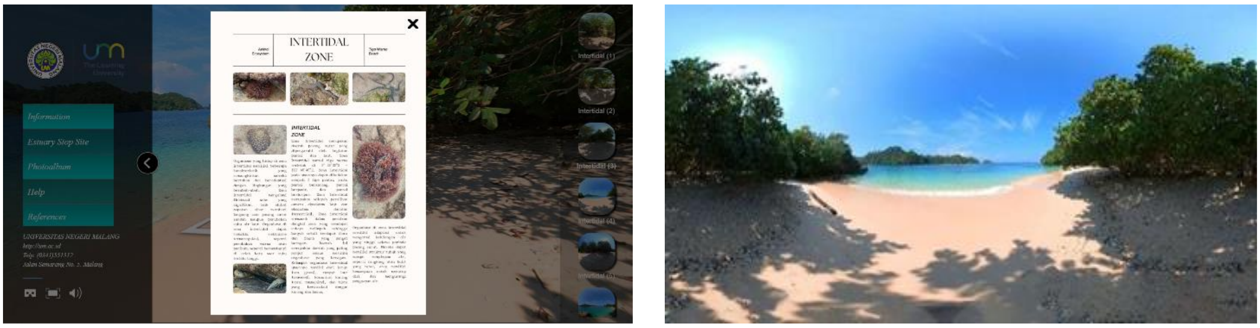


Figure 8. Spotsite 2 Mangrove Zone

Presentation of the next material content on the Virtual Reality Estuary media is a visualization of the environment in the mangrove zone area. Visualization in the form of a 360° panorama equipped with infographic information presentation as in Figure 8 Mangrove zone is one of the important topics in Geography. This is in line with the position of the mangrove zone which is able to become a learning resource for coastal and marine ecosystem studies (Aung et al., 2022). Through this lesson, students can understand the importance of preserving coastal and marine ecosystems (Sigit et al., 2020). Mangrove forests can be utilized as a case study in Geography learning (Sahrina et al., 2022). Using virtual reality technology as learning media can reveal phenomena in mangrove forests (Ou et al., 2021). Virtual Reality Estuary can provide information about the geographical conditions of the mangrove zone.



(a) Intertidal Zone Animal Ecosystem (b) Intertidal Zone Tidal Area

Figure 9. Spotsite 3 Intertidal Zone

Figure 9 (b) is a 360° panorama used in media development. Virtual Reality Estuary provides material content of the intertidal zone area. Figure 9 (a) shows information on the material content of the intertidal zone. The presentation of material content in the intertidal zone is based on the design of eco-spatial concepts and estuary conservation. Media supports virtual-based learning. Students can still explore the intertidal zone through Virtual Reality Estuary learning media that presents a 360° view (Meyer et al., 2019). The intertidal zone is a source of learning about coastal phenomena such as erosion, sedimentation, and sediment transport (Brand et al., 2019). In addition, the adaptation of organisms to the tidal environment is part of studying the intertidal zone (Leeuwis & Gamperl, 2022).

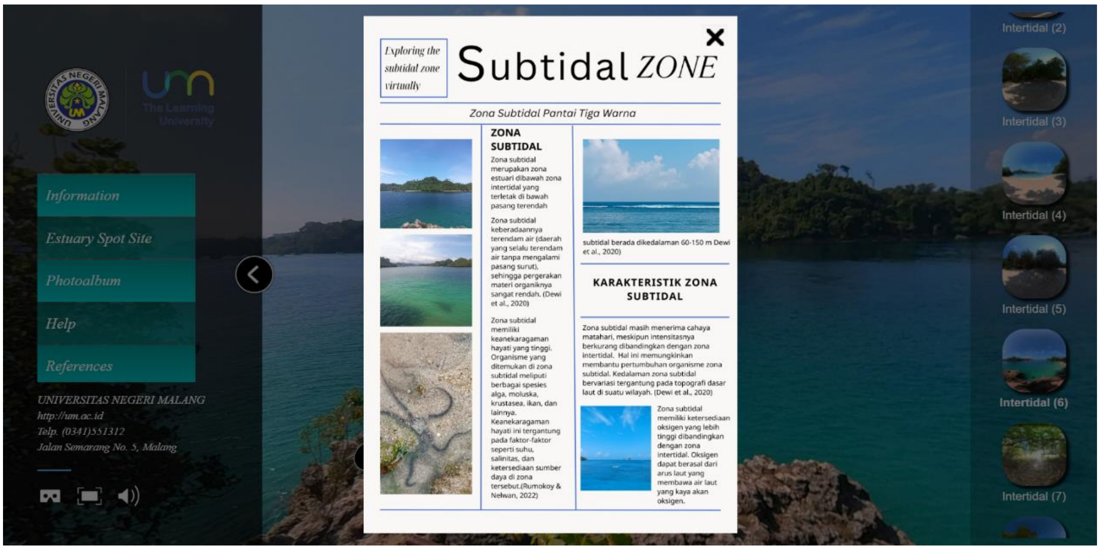


Figure 10 Spotsite 4 Subtidal Zone

The panorama of the Virtual Reality Estuary at spotsite 4 is the subtidal zone. Autostereoscopic 360° panorama helps students explore independently. Hotspots in the Virtual Reality Estuary contain information that becomes literacy material for students. The subtidal zone has a complex study in learning Geography (Bishop-Taylor et al., 2019). In addition, this zone is also a protected and restricted area for visits. This condition makes there are restrictions on direct field visits. So it is important to present material related to the subtidal zone into a virtual environment on the Virtual Reality Estuary media.

4. Conclusions

This research produces Virtual Reality Estuary learning media that has been declared valid and feasible in the learning process. Virtual Reality Estuary helps students in the learning process related to estuary. This study has pioneered the development of the Virtual Reality Estuary learning media, offering a transformative approach to address the challenges inherent in contextual Geography education. The immersive nature of the Virtual Reality Estuary platform holds promise for enhancing students' environmental consciousness, emphasizing the significance of estuary ecosystems in geographical pedagogy. Guided by the Successive Approximations Model, the research journey commenced with a rigorous needs analysis, leading to the creation of a media that simulates eco-spatial concepts and estuary conservation through an immersive 360° panorama. The content was meticulously curated, drawing insights from the Clungup Mangrove Conservation (CMC) region of Tiga Warna Beach. The conclusive evaluations attest to the efficacy of the Virtual Reality Estuary learning media in achieving its foundational objectives. However, its current application is confined to marine conservation material. Recognizing this limitation, it is imperative to expand its scope, integrating it into diverse subjects and modules pertinent to modern educational paradigms. Furthermore, future research should delve into gauging its long-term impact on learning outcomes and its potential adaptability across varied educational settings.

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