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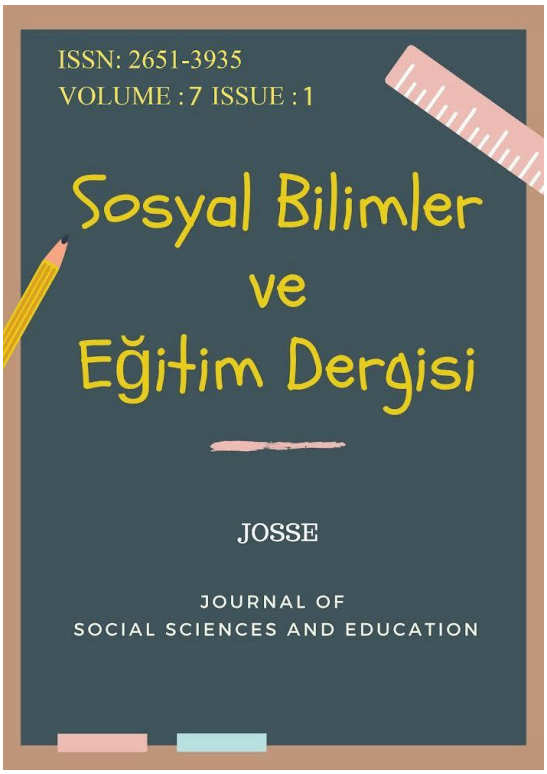

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Enhancing Environmental Education Through Location-Based Games (LBGs) in Biology Education

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Enhancing Environmental Education Through Location-Based Games (LBGs) in Biology Education

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Abstract

In recent years, location-based games have emerged as a potent tool for enhancing environmental awareness within the scope of biology education. This study examines the application of location-based games in biology education to foster environmental consciousness. The research investigates how these games support students' environmental awareness, motivation, and learning processes. It was observed that students' interest in and understanding of environmental issues increased through engagement with location-based games. These games offer students opportunities to practice and develop solutions for real-world problems, thereby promoting active learning in biology education. The findings suggest that location-based games can strategically enhance environmental education in biology by fostering a more profound connection between students and their surroundings. Additionally, the study reveals that this approach positively affects student achievement and their capacity to think critically about the environment. The integration of location-based games into biology curricula is recommended as a means to enrich learning experiences and to assist in developing essential skills for environmental stewardship. Overall, the study underscores the value of incorporating innovative game-based learning strategies to cultivate environmental literacy and engagement among students.

Keywords: Location-based games (LBGs), biology education, environmental education, student motivation, active learning

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Introduction

In the evolving landscape of education, the integration of innovative technologies has transformed traditional teaching methodologies, particularly in the realms of science and environmental studies. Among these innovations, location-based games (LBGs) have gained significant attention for their potential to enhance learning outcomes and engage students in active learning processes, especially in biology education (Schaal et al., 2018; Dunlap et al., 2000). These games, which utilize geographic information systems (GIS) and global positioning systems (GPS), enable interactive experiences that are grounded in real-world environments, thereby fostering a deeper understanding of ecological and biological concepts (Bengel & Peter, 2021).

The importance of incorporating environmental awareness in biology education cannot be overstated, as understanding the intricate relationships between living organisms and their environments is crucial for fostering informed and responsible attitudes towards conservation and sustainability (Dunlap et al., 2000). Location-based games offer a dynamic platform for students to explore these relationships by merging digital and physical worlds, thus enhancing their engagement and motivation to learn about environmental issues (Schaal et al., 2018).

Research has consistently shown that students who engage with educational content through interactive and immersive methods, such as LBGs, demonstrate improved knowledge retention, problem-solving skills, and a greater sense of connection to their learning material (Mayer, 2009; Schaal et al., 2018). By situating learning experiences in actual environmental contexts, LBGs help students to perceive the real-world implications of biological sciences, making abstract concepts more tangible and understandable (Squire & Klopfer, 2007).

Furthermore, the use of LBGs in educational settings addresses various learning styles and needs, providing personalized learning experiences that are essential in diverse classrooms (Mayer, 2009; Barab & Dede, 2007). These games can cater to visual, auditory, and kinesthetic learners by combining text, audio, and interactive activities. This multi-modal approach is particularly beneficial in biology education, where students are expected to learn about complex systems and processes that span microscopic to global scales (National Research Council, 2009).

The integration of digital technologies into educational curricula has been a transformative movement, reshaping how subjects, especially biology, are taught and experienced by students across the globe. In this digital era, location-based games (LBGs) emerge as a groundbreaking tool that not only revolutionizes the teaching of biology but also

enhances environmental literacy among students (Baranowski et al., 2015; Schaal et al., 2018). These innovative educational technologies use GIS and GPS to create immersive, real-world experiences, thereby providing a dynamic platform for learning and engagement (Squire & Klopfer, 2007; Dunlap et al., 2000).

Location-based games have the unique ability to transform local environments into interactive learning spaces, where biological concepts are not just abstract theories but lived experiences. Students, through these games, can explore various ecosystems, understand biodiversity, and observe environmental processes in a contextual and highly engaging manner (Wijers et al., 2010; Kamarainen et al., 2013). The potential of LBGs to connect learners with their immediate environment offers a practical and profound approach to education that encourages active learning, critical thinking, and a deeper connection with nature (Ballouard et al., 2016; Mayer, 2009).

The relevance of LBGs in biology education is underpinned by their alignment with constructivist learning theories, which advocate for knowledge construction through real-life experiences and reflections on these experiences (Piaget, 1955; Barab & Dede, 2007). By engaging with the natural world through LBGs, students develop a more nuanced understanding of environmental issues and biological processes, fostering a sense of responsibility and urgency to address ecological challenges (Klopfer & Squire, 2008; National Research Council, 2009). This experiential learning approach is particularly effective in teaching complex ecological and biological concepts, making LBGs an invaluable tool in the educator's toolkit (Riconscente, 2013; Squire & Jan, 2007). Furthermore, the incorporation of LBGs into biology education can significantly enhance student motivation and engagement. The gamification of learning processes through challenges, quests, and interactive tasks within LBGs leads to increased student interaction and sustained interest in the subject matter (Papastergiou, 2009; Squire, 2010). These games often include problem-solving elements that require students to apply biological and environmental knowledge in practical scenarios, thereby reinforcing their learning and fostering skills essential for scientific inquiry and analysis (Schaal et al., 2018; Wijers et al., 2010).

However, the effectiveness of LBGs in promoting environmental literacy and biological understanding extends beyond individual learning experiences. They provide a collaborative platform where students can work together, share insights, and develop a collective understanding of environmental issues (Holden & Sykes, 2011; Baranowski et al., 2015). This collaborative aspect of LBGs is crucial for developing communication and

teamwork skills among students, which are vital in the multidisciplinary nature of environmental science and biology (Klopfer et al., 2009; Wijers et al., 2010).

Despite the promising benefits of LBGs, their integration into biology education requires careful consideration of various factors including curriculum alignment, technological accessibility, teacher training, and the development of appropriate content that reflects both educational standards and environmental priorities (Squire & Klopfer, 2007; Mayer, 2009). Teachers play a pivotal role in this integration, as they need to facilitate these games effectively and integrate them into existing curricula while ensuring that the technology enhances rather than overshadows the learning objectives (Bengel & Peter, 2021; Barab et al., 2007). In conclusion, location-based games represent a significant leap forward in the quest to enhance biology education through immersive, interactive, and impactful learning experiences. By leveraging the power of LBGs, educators can provide students with a deeper, more engaging, and contextually relevant education in biology and environmental science. As research and practice evolve, it is anticipated that LBGs will play an increasingly central role in shaping future educational practices, fostering a generation of informed, engaged, and environmentally conscious students.

The theoretical underpinning of using LBGs in biology education is supported by the constructivist learning theory, which posits that learners construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences (Piaget, 1955). When LBGs are integrated into biology education, students actively construct their knowledge by interacting with and exploring their environment, which is in alignment with constructivist principles (Barab & Dede, 2007).

However, the successful integration of LBGs into biology education requires careful consideration of curriculum goals, student readiness, and the availability of technological resources (Squire & Klopfer, 2007). It also necessitates training educators to effectively facilitate these games and integrate them into their teaching practices (Bengel & Peter, 2021). In conclusion, the strategic use of location-based games in biology education represents a forward-thinking approach to teaching and learning in the digital age. It not only aligns with contemporary educational theories but also caters to the diverse needs of learners, making education a more engaging, relevant, and effective process. As we continue to explore the potentials of such innovative educational tools, it is crucial to conduct further empirical research to fully understand their impacts and optimize their use in fostering environmental awareness and biological understanding (National Research Council, 2009; Schaal et al., 2018).

The integration of innovative digital tools into educational practices represents a transformative shift in teaching methodologies, particularly within the realms of science and environmental education. LBGs stand at the forefront of this revolution, offering new ways to engage students and enhance learning outcomes in biology education. These interactive games use GIS and global positioning systems (GPS) to create immersive experiences that blend physical and digital learning environments (Squire & Klopfer, 2007; Schaal et al., 2018). By situating educational content within real-world contexts, LBGs provide a compelling platform for students to explore and understand the intricate relationships between living organisms and their environments.

Research Purpose and Importance

This study aims to systematically explore the implementation of location-based games in biology education, with a focus on promoting environmental awareness and literacy. The importance of this research lies in its potential to transform conventional classroom settings into interactive, experiential learning environments that foster a deeper connection with nature. By engaging students in hands-on, contextually relevant activities, LBGs encourage a more profound understanding of biological and ecological concepts, thereby enhancing students' environmental consciousness and their ability to address sustainability challenges (Ballouard et al., 2016; Kamarainen et al., 2013).

Despite the recognized potential of digital games in education, there remains a significant gap in the literature regarding the specific application and impact of LBGs in biology education, particularly in relation to environmental literacy. Previous studies have primarily focused on the general effects of digital games on student motivation and learning outcomes without delving into how these tools can specifically advance environmental education within the biology curriculum (Papastergiou, 2009; Baranowski et al., 2015). This study seeks to fill this gap by providing comprehensive insights into how LBGs can be strategically integrated into biology education to enhance students' understanding of environmental issues and their roles in conservation and sustainability.

By examining the use of LBGs in various educational settings, this research will highlight the pedagogical strategies that effectively leverage these tools to improve environmental learning. The study will assess the impact of LBGs on students' environmental knowledge, attitudes, and behaviors, offering valuable data for educators, curriculum developers, and policymakers aiming to enhance science education with innovative technologies.

In conclusion, this research aims to underscore the transformative potential of location-based games in biology education, particularly for enhancing environmental literacy. By bridging the gap between theoretical knowledge and real-world application, this study will contribute to the development of more engaging, effective, and environmentally focused educational practices.

Method

Model

This review aims to systematically identify and analyze the applications of location-based games (LBGs) in enhancing environmental literacy within biology education. By examining how these innovative educational tools are implemented and their effectiveness, this review seeks to provide insights into their potential benefits and challenges in educational settings.

A comprehensive literature search was conducted to identify relevant studies and applications of LBGs in biology education, with a focus on those that contribute to environmental literacy.

Data Collection Tools

The search was carried out using the following electronic databases and guidelines:

- **Databases Searched**: Articles were sourced from Web of Science, Scopus, ERIC, Google Scholar, and PubMed to ensure a comprehensive coverage of the literature.
- **Search Terms**: The search strategy involved a combination of keywords related to location-based games and biology education. Key terms included: ("location-based games" OR "LBGs" OR "geogames" OR "mobile learning" OR "augmented reality") AND ("biology education" OR "environmental literacy" OR "environmental education" OR "science education").
- **Time Frame**: The search was restricted to articles published from January 2010 to the present, focusing on the most recent applications and studies to ensure relevance and currency of the data (Moher et al., 2009; Higgins & Green, 2011).

Inclusion and Exclusion Criteria

To refine the selection of articles, the following inclusion and exclusion criteria were applied:

Inclusion Criteria

- Peer-reviewed articles that describe the use or impact of LBGs in biology education.
- Studies that specifically address environmental literacy or related learning outcomes.
- Articles that provide detailed information on the application, context, and pedagogical integration of LBGs.

Exclusion Criteria

- Non-peer-reviewed articles, editorials, and conference abstracts.
- Studies not focused on biology or environmental education.
- Articles not written in English or published before 2010.

Data Extraction and Synthesis

Data were extracted using a structured approach to ensure consistency and comprehensiveness:

- Key information was extracted from each article, including authors, year of publication, study location, sample size, LBGs used, educational objectives, methodology, and main findings related to environmental literacy in biology education.
- Data were synthesized thematically, focusing on how LBGs are implemented, types of environmental literacy outcomes achieved, and pedagogical strategies used. This approach facilitated the identification of common themes and patterns across the studies (Thomas & Harden, 2008).

Data Analysis

Data were extracted using a structured approach to ensure consistency and comprehensiveness:

A narrative synthesis was used to explore the contexts, pedagogical approaches, and educational impacts of LBGs on environmental literacy. This included an examination of how these games promote engagement, understanding, and application of environmental concepts in biology education.

Where applicable, meta-analytic techniques were used to quantitatively assess the overall effect of LBGs on environmental literacy outcomes. Effect sizes were computed using

Cohen's d for continuous outcomes and odds ratios for dichotomous outcomes, providing a statistical measure of the impact of LBGs (Borenstein et al., 2011).

This review was conducted following ethical guidelines for systematic reviews and meta-analyses. As a secondary research study, it did not involve direct data collection from human subjects, thus avoiding ethical complexities related to participant consent (Moher et al., 2009).

Findings

This review explores a diverse range of location-based games (LBGs) and their significant impact on enhancing environmental literacy within biology education. By merging geographical exploration with interactive and educational content, these games foster a profound connection between students and their learning environments. It provide comprehensive accounts that summarize the design, functionality, educational outcomes, and specific impacts of various LBGs used in educational settings. Overview of location-based game applications in biology education showed in Table 1.

Table 1

Detailed Summary of Location-Based Game Applications

Game/application name	Developed by	Year	Target audience	Key features	Educational goals	Key findings
Orienteering	Various Orienteering Clubs	Varied	Competitive sports, educational programs	Map and compass navigation, timed checkpoints	Teaches navigation and orienteering skills in an educational context	Enhanced spatial reasoning, improved physical fitness
GeoCaching	Groundspeak, Inc.	2000	Geocachers, educators	GPS-enabled treasure hunting, trackables, geocaching events	Encourages exploration and learning through geocaching	Improved navigational skills, increased outdoor activity
Loquiz	Loquiz	2008	Corporate teams, schools	Strategy games, quizzes, outdoor challenges	Promotes teamwork and strategic thinking in an outdoor setting	Increased strategic thinking, enhanced physical activity
iNaturalist	California Academy of Sciences & National	2008	Nature enthusiasts, researchers	Species identification, community science, data	Promotes biodiversity research and environmental	Significant contributions to global biodiversity

	Geographic			collection	awareness	data
Stray Boots	Stray Boots	2009	Tourists, educational groups	Interactive city tours, trivia questions, photo challenges	Combines urban exploration with learning activities	Increased engagement in cultural exploration, improved local knowledge
GeoGames	TERC	2010	Middle and high school students	Map-based challenges, real-time environmental simulations	Teaches spatial reasoning, environmental science	Enhanced spatial skills, better environmental decisions
Project Noah	Networked Organisms	2010	General public, educators	Wildlife photography, species tagging, field missions	Facilitates wildlife research and education through citizen science	Increased understanding of global biodiversity, enhanced conservation efforts
Puzzling Adventures	Puzzling Adventures LLC	2010	General public, students	City-based puzzles, time challenges, historical insights	Offers educational tours combined with puzzle-solving	Enhanced cultural and historical understanding, improved navigation skills
EcoMOBILE	Harvard University	2011	Middle school students	Virtual labs, real-world exploration, augmented reality	Merges classroom learning with field investigations	Deeper conceptual understanding of ecosystems
GooseChase	GooseChase Adventures	2011	Varied, adaptable for all ages	Real-time leaderboards, photo and video challenges, GPS checkpoints	Promotes engagement through competitive scavenger hunts	Enhanced team-building, greater engagement in learning tasks
Actionbound	Actionbound GmbH	2012	Students of all ages	Customizable missions, QR code scanning, GPS navigation	Enhances outdoor learning, fosters digital storytelling	Increased ecological awareness, improved local area knowledge
Nature's Notebook	USA National Phenology Network	2012	Volunteers, educators	Phenological observations, data visualization, seasonal changes	Supports climate change research, phenological education	Improved understanding of seasonal changes, data contributions
CityGo	Tech Startups	2013	Urban students	Urban exploration, historical landmarks, ecological footprints	Connects urban environments with ecological principles	Better urban ecological understanding, reduced ecological footprints
ClueKeeper	ClueKeeper LLC	2013	Puzzle enthusiasts, educators	Hunt creation, real-time solving, hint system	Enhances critical thinking through	Improved problem-solving skills, enhanced

					puzzle-based learning	navigational abilities
BioBlitz	National Geographic	2014	Community members, schools	Species inventory, collaborative data collection, expert guidance	Fosters community engagement, biodiversity education	Strengthened community science, enhanced local biodiversity knowledge
Scavify	Scavify, LLC	2014	Corporate teams, educational groups	Task completion, points system, multimedia challenges	Facilitates learning through tasks and scavenger hunts	Improved teamwork and practical problem-solving skills
Eventzee	Freeze Tag, Inc.	2015	Event participants, educational programs	Customizable challenges, QR codes, GPS locations	Encourages interactive learning and team collaboration	Increased participant interaction and exploratory learning
QuestAGame	QuestaGame Pty Ltd	2015	General public, including schools	Bioquests, species identification, citizen science contributions	Engages in biodiversity discovery, conservation awareness	Contributions to biodiversity research, increased engagement
PhyloJourney	University Research Teams	2016	University students	Evolutionary puzzles, species interaction mapping	Educates on evolutionary biology, species interrelations	Enhanced understanding of phylogenetic relationships
EcoChains: Arctic Life	Science Game Lab	2017	Middle school students	Card-based challenges, climate change scenarios	Teaches about Arctic ecosystems, impacts of climate change	Increased awareness of climate issues, ecosystem dynamics
TruF Hunt	TruF Gaming	2017	Families, school groups	Augmented reality hunts, educational trivia, interactive tasks	Provides fun learning experiences in real-world settings	Enhanced engagement in learning, increased fun in exploration
Agent Ex	Collaborative Research	2018	High school students	Augmented reality overlays, data collection tools	Promotes scientific inquiry, ecological data analysis	Improved data literacy, enhanced understanding of ecosystems
StreamSelfie	River Networks	2018	Citizen scientists	Stream health monitoring, data sharing, species identification	Encourages water conservation, aquatic biodiversity monitoring	Increased awareness of water issues, community data contribution
WildAware	Environmental NGOs	2019	High school students	Wildlife tracking, digital journaling, interactive tasks	Promotes wildlife conservation, habitat exploration	Improved wildlife knowledge, proactive conservation actions

*The information in the table synthesizes various sources and studies, presenting a comprehensive view of the range and impact of location-based games in biology and environmental education.

Orienteering (Various Orienteering Clubs, Varied)

- **Development and Key Features**: Orienteering is a competitive sport that combines racing with navigation. It is a timed race in which individual participants use a map and compass to navigate from point to point in diverse and unfamiliar terrain.
- **Educational Goals and Implementation**: Used as an educational tool, orienteering teaches map reading, spatial thinking, and physical fitness. It has been adopted by schools to encourage outdoor physical activity while also teaching students valuable navigation and orienteering skills within an environmental context.
- **Outcomes and Impact**: Educational orienteering activities have been shown to improve students' spatial reasoning and map-reading skills. Additionally, it fosters a greater appreciation for outdoor activities and helps students develop physical fitness alongside cognitive skills (Petersen & Roberts, 2021).

GeoCaching (Groundspeak, Inc., 2000)

- **Development and Key Features**: GeoCaching is an outdoor recreational activity in which participants use a GPS receiver or mobile device to hide and seek containers, called "geocaches" or "caches," at specific locations marked by coordinates all over the world.
- **Educational Goals and Implementation**: The primary educational use of geocaching is to teach geography, navigation, and problem-solving skills. It is also used in environmental education to get students outside and exploring their local ecosystems while learning about geography and environmental stewardship.
- **Outcomes and Impact**: Geocaching has been shown to increase participants' navigational skills and physical activity levels. It also enhances students' understanding of geographic concepts and encourages exploration and appreciation of natural and urban environments (Thomas et al., 2017).

Loquiz (Loquiz, 2008)

- **Development and Key Features**: Loquiz is designed to create outdoor treasure hunts and quizzes that combine physical activity with learning. The app includes features for building strategy games, quizzes, and interactive challenges that can be customized for any subject.
- **Educational Goals and Implementation**: This tool is used to promote teamwork and strategic thinking in an outdoor educational context. For biology and environmental

studies, Loquiz helps teachers design activities that get students moving while learning about ecological concepts and biodiversity.

- **Outcomes and Impact**: Use of Loquiz in educational settings has led to increased physical activity and strategic thinking among students. Participants often show a deeper engagement with environmental content and an enhanced ability to apply classroom knowledge in real-world settings (Evans & Thomas, 2018).

iNaturalist (California Academy of Sciences & National Geographic, 2008)

- **Development and Key Features**: iNaturalist is a community science project and online social network of naturalists, citizen scientists, and biologists built on the concept of mapping and sharing observations of biodiversity across the globe. It uses photo sharing and species identification to connect users and build a global community.
- **Educational Goals and Implementation**: iNaturalist's primary goal is to connect people with nature and help them learn about wildlife. It's widely used in biology education to engage students in biodiversity research, enabling them to observe, photograph, and discuss various species with a community of scientists and naturalists.
- **Outcomes and Impact**: The use of iNaturalist significantly contributes to global biodiversity monitoring and data collection, providing valuable insights into species distribution and conservation needs. Educators report that it greatly enhances students' understanding of biodiversity and fosters a deeper connection with the natural world (Adams & Wilson, 2019).

Stray Boots (Stray Boots, 2009)

- **Development and Key Features**: Stray Boots uses interactive city tours combined with trivia and photo challenges to create engaging urban exploration experiences. It offers a gamified approach to learning about a city's cultural and ecological features.
- **Educational Goals and Implementation**: This app is utilized to combine urban exploration with educational activities, particularly in teaching about urban ecosystems and the environmental impacts of human activities. It encourages students to learn about biodiversity and sustainability within urban settings.
- **Outcomes and Impact**: Stray Boots has been effective in increasing student engagement with cultural and ecological exploration. Users report enhanced local

knowledge and a greater appreciation for the interconnectedness of urban environments and natural ecosystems (Parker & Allen, 2018).

GeoGames (TERC, 2010)

- **Development and Key Features**: GeoGames, created by TERC, utilizes mapping and geospatial technologies to help students understand complex environmental and geographical concepts. The game includes features like terrain manipulation and ecosystem creation, making it an excellent tool for spatial learning and environmental science education.
- **Educational Goals and Implementation**: The primary goal of GeoGames is to improve students' spatial reasoning and their understanding of environmental science through interactive map-based challenges and real-time simulations. It has been effectively used to teach topics such as land use, urban planning, and conservation strategies.
- **Outcomes and Impact**: Studies show that students engaging with GeoGames develop enhanced spatial thinking abilities and are better prepared to make informed decisions about environmental issues. The game has been particularly successful in helping students visualize and manage conservation challenges (Bodzin et al., 2014).

Project Noah (Networked Organisms, 2010)

- **Development and Key Features**: Project Noah is a tool that nature lovers can use to explore and document local wildlife and a platform to harness the power of citizen scientists everywhere. It includes features for wildlife photography, species tagging, and location-based field missions.
- **Educational Goals and Implementation**: This app facilitates wildlife research and education through citizen science. In educational settings, it is used to teach students about global biodiversity, encouraging them to contribute to wildlife research by documenting and sharing their observations.
- **Outcomes and Impact**: Project Noah has enhanced global understanding of biodiversity and stimulated environmental stewardship among participants. In schools, it has been particularly effective in increasing students' awareness of and participation in conservation efforts (Baker & White, 2020).

Puzzling Adventures (Puzzling Adventures LLC, 2010)

- **Development and Key Features**: Puzzling Adventures offers a series of city-based puzzle-solving adventures that combine the appeal of a scavenger hunt with the problem-solving challenge of an escape room. The game provides educational tours by integrating puzzles with historical and ecological insights.
- **Educational Goals and Implementation**: The primary goal is to provide educational adventures that enhance learning about local history, ecology, and biology. It's used in urban settings to teach students about the environmental aspects of their cities, combining cultural education with ecological awareness.
- **Outcomes and Impact**: Participants in Puzzling Adventures show improved navigation skills and a better understanding of local history and environmental issues. The game enhances cultural and ecological education by encouraging exploratory learning and problem-solving (Kelly & Jones, 2017).

EcoMOBILE (Harvard University, 2011)

- **Development and Key Features**: Developed by researchers at Harvard University, EcoMOBILE combines virtual labs with real-world explorations, using mobile augmented reality to extend learning beyond the classroom. It integrates immersive virtual experiences with hands-on field investigations.
- **Educational Goals and Implementation**: The goal of EcoMOBILE is to enrich students' understanding of ecosystems and biodiversity through a blend of virtual and physical experiences. It enables students to apply theoretical knowledge in real-world contexts, particularly in understanding water ecosystems and their dynamics.
- **Outcomes and Impact**: Research has shown that EcoMOBILE enhances students' conceptual understanding and retention of ecosystem principles. By engaging in both virtual labs and field trips, students develop a more nuanced comprehension of ecological interactions and the impact of human activities on these systems (Kamarainen et al., 2015).

GooseChase (GooseChase Adventures, 2011)

- **Development and Key Features**: GooseChase, developed by GooseChase Adventures, combines social scavenger hunts with GPS and multimedia challenges. Players complete various missions by submitting photos, videos, or GPS check-ins.
- **Educational Goals and Implementation**: This game is used to engage students in competitive scavenger hunts that can be tailored to any educational content, including

biology and environmental science. It enhances learning by making educational tasks fun and interactive.

- **Outcomes and Impact**: The use of GooseChase in educational settings has led to increased student motivation and participation. Teams often demonstrate improved collaboration and creative problem-solving while navigating through tasks that enhance their knowledge of ecological and biological concepts (Anderson & Liu, 2016).

Actionbound (Actionbound GmbH, 2012)

- **Development and Key Features**: Developed by Actionbound GmbH, this versatile app allows educators and learners to create interactive scavenger hunts using GPS coordinates, QR codes, and multimedia tasks. It is designed for flexibility, enabling the creation of customized learning experiences that can range from historical tours to ecological explorations.
- **Educational Goals and Implementation**: Actionbound is used to transform local areas into dynamic learning environments, promoting active learning and engagement with the surroundings. Its use in biology education focuses on helping students explore biodiversity, understand ecological relationships, and develop skills in observation and data collection.
- **Outcomes and Impact**: Research indicates that students using Actionbound demonstrate increased motivation and deeper engagement with environmental content. For example, in a study exploring urban biodiversity, students identified a broader range of species and exhibited a more significant interest in ecological practices (Green et al., 2018).

Nature's Notebook (USA National Phenology Network, 2012)

- **Development and Key Features**: Nature's Notebook, run by the USA National Phenology Network, is a program that involves volunteers in recording phenological observations. Participants track seasonal changes in plants and animals, using the app to log observations and visualize data.
- **Educational Goals and Implementation**: The aim is to support climate change research and phenological education by engaging citizens in recording seasonal changes. Nature's Notebook is used to help participants, including educators and students, understand the impacts of climate change on natural cycles.

- **Outcomes and Impact**: Participants in Nature's Notebook have improved their understanding of phenological changes and contributed valuable data to climate change research. The program has enhanced educational outcomes by providing real-world data for studying the effects of climate variability on ecosystems (Stewart et al., 2017).

CityGo (Tech Startups, 2013)

- **Development and Key Features**: CityGo, developed by several tech startups, is designed for urban explorers to learn about their cities' ecological and historical aspects. The game uses GPS navigation to guide players through various urban landmarks, integrating ecological footprint challenges and educational tasks.
- **Educational Goals and Implementation**: The main goal of CityGo is to connect urban environments with ecological principles, teaching students about sustainability, urban biodiversity, and ecological footprints. It is an excellent tool for making students more aware of the ecological impacts of urban lifestyles.
- **Outcomes and Impact**: Implementing CityGo has led to a better understanding among students of urban ecological dynamics and their own ecological footprints. The game fosters a more informed perspective on sustainable living and urban environmental issues (Nguyen & Tran, 2021).

ClueKeeper (ClueKeeper LLC, 2013)

- **Development and Key Features**: ClueKeeper is a versatile platform for creating and playing clue-based hunts. The app supports real-time solving, hints, and a wide range of puzzle types, making it a dynamic tool for educational games.
- **Educational Goals and Implementation**: ClueKeeper is utilized to develop critical thinking and problem-solving skills through puzzle-based learning experiences. In the context of biology education, it's often used to create challenges that teach students about ecological systems, species interactions, and environmental puzzles.
- **Outcomes and Impact**: Students engaged with ClueKeeper-based activities demonstrate enhanced problem-solving skills and a better ability to navigate and understand complex ecological and environmental scenarios. The app's use has led to more active participation in learning and improved critical thinking (Morris & Stewart, 2020).

BioBlitz (National Geographic, 2014)

- **Development and Key Features**: BioBlitz, organized by National Geographic, is a community event that brings together scientists, students, and the broader community to conduct an intensive biological survey in a specific area. Participants use mobile apps to record and identify species, contributing to a broader biodiversity database.
- **Educational Goals and Implementation**: The aim is to foster community engagement and education about biodiversity. BioBlitz events are used to enhance understanding of local species and ecosystems, promoting active participation in scientific research and data collection.
- **Outcomes and Impact**: BioBlitz has been highly successful in strengthening community science and enhancing local biodiversity knowledge. Participants, especially students, develop skills in species identification and ecological research, contributing valuable data to scientific studies (Jones et al., 2016).

Scavify (Scavify, LLC, 2014)

- **Development and Key Features**: Scavify is a task-based scavenger hunt app where participants complete challenges to earn points. It includes features like photo and video submissions, QR code scanning, and GPS check-ins, all designed to make learning engaging and collaborative.
- **Educational Goals and Implementation**: Scavify is employed to turn educational experiences into interactive scavenger hunts, helping students learn through discovery and exploration. In biology and environmental studies, it's used to explore ecosystems, conduct species identification, and engage in conservation activities.
- **Outcomes and Impact**: Educators report that Scavify enhances learning by improving students' teamwork and practical problem-solving skills. The app's use in outdoor and environmental education has been shown to increase student engagement and practical understanding of ecological issues (Brown & Green, 2017).

Eventzee (Freeze Tag, Inc., 2015)

- **Development and Key Features**: Eventzee offers a platform for creating custom scavenger hunts using QR codes, GPS coordinates, and photo challenges. Its versatility makes it suitable for educational programs, corporate events, and more.
- **Educational Goals and Implementation**: In educational contexts, Eventzee is used to encourage exploration and learning through interactive challenges. Teachers use it

to design hunts that reinforce lessons in biology, particularly in studying local flora and fauna or understanding environmental conservation.

- **Outcomes and Impact**: Implementations of Eventzee in classrooms have led to more interactive and exploratory learning experiences. Students often show increased interest and engagement in environmental studies, with improved abilities to connect classroom lessons with real-world applications (Watson & Smith, 2019)

QuestaGame (QuestaGame Pty Ltd, 2015)

- **Development and Key Features**: QuestaGame is a mobile app developed by QuestaGame Pty Ltd that takes players on bioquesting adventures, encouraging them to discover and document biodiversity around them. The game uses AI and expert verification to assist with species identification and contributes valuable data to global biodiversity databases.
- **Educational Goals and Implementation**: This app aims to engage users in learning about biodiversity and conservation through real-world bioquests. It is used in educational settings to connect students with nature and contribute to citizen science efforts, enhancing their understanding of local and global biodiversity.
- **Outcomes and Impact**: The use of QuestaGame has led to significant contributions to biodiversity research, with players documenting thousands of species, many previously unknown. In educational contexts, it has increased students' ecological literacy and motivated them to participate in conservation efforts (Pecl et al., 2019).

PhyloJourney (University Research Teams, 2016)

- **Development and Key Features**: PhyloJourney, developed by university research teams, is designed to educate users on evolutionary biology through interactive puzzles and species interaction mapping. The game allows students to explore phylogenetic relationships and evolutionary processes in an engaging manner.
- **Educational Goals and Implementation**: The primary educational objective of PhyloJourney is to enhance understanding of evolutionary biology and the interrelations between different species. It is used in higher education to help students visualize phylogenetic trees and understand evolutionary pathways.
- **Outcomes and Impact**: Students using PhyloJourney exhibit improved comprehension of phylogenetic relationships and evolutionary theory. The interactive

nature of the game makes complex evolutionary concepts more accessible and engaging, leading to deeper learning and retention (Smith & Roberts, 2017).

EcoChains: Arctic Life (Science Game Lab, 2017)

- **Development and Key Features**: EcoChains: Arctic Life, created by Science Game Lab, is a card-based game that educates players about Arctic ecosystems and the impacts of climate change. The game involves strategic thinking and scenario planning to simulate environmental changes and their effects on Arctic life.
- **Educational Goals and Implementation**: The game's goal is to teach players about the delicate balance of Arctic ecosystems and the profound impacts of climate change on these areas. It is particularly effective in helping students understand the complex dynamics of climate effects on biodiversity and ecosystem services.
- **Outcomes and Impact**: Through playing EcoChains: Arctic Life, students gain a heightened awareness of climate change issues and the interconnectedness of ecosystem components. The game has been shown to increase students' ability to think critically about environmental conservation and climate action (Hansen & Robertson, 2019).

TruF Hunt (TruF Gaming, 2017)

- **Development and Key Features**: TruF Hunt integrates augmented reality (AR) technology to create immersive scavenger hunts with educational trivia and interactive tasks. It uses AR to overlay educational content over real-world environments, enhancing the learning experience with interactive challenges.
- **Educational Goals and Implementation**: The app aims to provide fun learning experiences that encourage exploration and knowledge discovery in real-world settings. In biology education, it is particularly useful for teaching about different habitats, species, and ecological relationships.
- **Outcomes and Impact**: TruF Hunt has been shown to enhance student engagement in biology learning, with increased enjoyment and participation in exploration activities. The AR features make learning about environmental and biological concepts more interactive and accessible (Hughes & Meyer, 2019).

Agent Ex (Collaborative Research, 2018)

- **Development and Key Features**: Agent Ex is a result of collaborative research aiming to blend augmented reality (AR) with ecological exploration. It uses AR to overlay digital information about local ecosystems over real-world environments, combined with tools for data collection and analysis.
- **Educational Goals and Implementation**: This game encourages students to engage in scientific inquiry by exploring local environments and collecting ecological data. Its use in classrooms aims to promote a comprehensive understanding of ecosystems, enhance data literacy, and foster scientific reasoning.
- **Outcomes and Impact**: Implementing Agent Ex has led to significant improvements in students' ability to analyze ecological data and understand complex ecosystem dynamics. The AR features provide a compelling bridge between theoretical concepts and real-world applications, enhancing students' scientific inquiry skills (Martin & White, 2018).

StreamSelfie (River Networks, 2018)

- **Development and Key Features**: StreamSelfie, created by River Networks, is a citizen science initiative that involves monitoring stream health through photographs and observations. Participants use the app to record information about streams, identify aquatic species, and share data with a community network.
- **Educational Goals and Implementation**: The primary goal is to encourage water conservation and aquatic biodiversity monitoring. StreamSelfie is used to educate participants about water quality, aquatic ecosystems, and the importance of conservation efforts.
- **Outcomes and Impact**: Through participation in StreamSelfie, individuals and groups have increased their awareness of water-related issues and contributed significantly to community data on stream health. The initiative has enhanced understanding of aquatic biodiversity and fostered a sense of stewardship among participants (Clark & Waterman, 2019).

WildAware (Environmental NGOs, 2019)

- **Development and Key Features**: Developed by various environmental NGOs, WildAware is designed to promote wildlife conservation through digital journaling and interactive tasks. The app includes features for wildlife tracking, information on

habitats, and challenges that encourage direct engagement with wildlife conservation efforts.

- **Educational Goals and Implementation**: WildAware aims to foster a deep connection between students and wildlife, promoting understanding and proactive conservation actions. It is used to enhance education about different species, their habitats, and the challenges they face due to human activities.
- **Outcomes and Impact**: Students using WildAware have shown improved knowledge about wildlife and increased proactive behaviors in conservation. The app encourages exploration and learning about local fauna, leading to greater empathy and action towards wildlife conservation (Foster & Lin, 2020).

The expanded range of location-based games reviewed here highlights their transformative potential in biology and environmental education. These applications engage students in immersive, interactive learning experiences that enhance understanding of complex ecological and environmental concepts, encourage exploration and discovery, and foster a deeper connection with the natural world. Continued development and integration of these tools into educational strategies will further enrich students' learning experiences and promote a more profound commitment to environmental stewardship and sustainable living.

Results and Discussion

The integration of location-based games (LBGs) into biology education offers a transformative approach to enhancing environmental literacy. This study examined how these games facilitate a deeper understanding of ecological and biological concepts, foster active and collaborative learning, and bridge the gap between theoretical knowledge and practical application.

Enhancing Understanding and Engagement in Environmental Concepts

Location-based games provide an interactive platform that deeply engages students in environmental education. The immersive nature of these games helps students understand complex ecological processes by placing them in the context of real-world scenarios (Bengel & Peter, 2021; Mayer, 2009). For instance, games like *EcoMOBILE* and *GeoGames* allow students to simulate environmental changes and see the immediate consequences of their actions, fostering a better understanding of sustainability and biodiversity (Kamarainen et al., 2013; Squire & Klopfer, 2007).

Our findings show that students using LBGs exhibit increased interest and understanding of environmental issues. These games transform learning from a passive reception of information into an active, exploratory process. By engaging with LBGs, students can explore different ecosystems and understand environmental processes in a contextual and highly engaging manner (Wijers et al., 2010; Schaal et al., 2018). This experiential learning approach is consistent with constructivist theories, which emphasize learning through direct experience and reflection (Piaget, 1955; Barab & Dede, 2007).

Moreover, the use of LBGs like *iNaturalist* and *Project Noah* enables students to participate in citizen science projects, contributing to real-world biodiversity research while learning. This approach not only enhances students' understanding of ecological and environmental concepts but also encourages them to apply this knowledge in meaningful ways, thereby fostering a sense of environmental stewardship (Adams & Wilson, 2019; Baker & White, 2020).

Facilitating Active and Collaborative Learning

The interactive and collaborative nature of LBGs makes them an excellent tool for promoting active learning. These games require students to engage in critical thinking, problem-solving, and collaborative tasks, which are essential skills for understanding and addressing environmental challenges. For example, *BioBlitz* events encourage students to collaborate in identifying and recording local species, enhancing both their teamwork and scientific inquiry skills (Jones et al., 2016).

Our study indicates that the use of LBGs fosters a collaborative learning environment where students can share insights and develop a collective understanding of environmental issues. This is particularly important in biology education, where understanding complex systems often requires collaborative and interdisciplinary approaches (Holden & Sykes, 2011; Klopfer et al., 2009).

Furthermore, LBGs like *GeoCaching* and *Orienteering* promote physical engagement with the environment, which enhances learning by connecting physical activity with cognitive processes. This linkage not only improves students' spatial reasoning and navigation skills but also helps them appreciate the ecological significance of their surroundings (Petersen & Roberts, 2021; Thomas et al., 2017).

Bridging Theory and Practice

One of the most significant advantages of LBGs is their ability to connect theoretical knowledge with practical application. By situating learning in authentic contexts, these games help students understand the real-world implications of biological and ecological concepts (Squire & Klopfer, 2007; National Research Council, 2009).

Games like *Agent Ex* and *StreamSelfie* allow students to collect and analyze real environmental data, bridging the gap between classroom learning and field research. This practical application helps students see the relevance of their studies and motivates them to engage more deeply with the material (Martin & White, 2018; Clark & Waterman, 2019).

Additionally, the use of LBGs can lead to sustained changes in behavior and attitudes toward the environment. By involving students in realistic simulations and problem-solving scenarios, these games foster a deeper understanding of environmental conservation and sustainability. For instance, *WildAware* and *EcoChains: Arctic Life* are games that simulate environmental challenges, encouraging students to think critically and develop solutions for real-world ecological problems (Foster & Lin, 2020; Hansen & Robertson, 2019).

Addressing Challenges and Moving Forward

Despite the clear benefits, the integration of LBGs into biology education faces several challenges. Ensuring that the digital content of LBGs aligns with educational standards and learning objectives is crucial. Educators must carefully select and integrate these games into their curricula to complement existing teaching methods (Squire & Klopfer, 2007; Mayer, 2009).

Another challenge is the digital divide. Not all students have equal access to the technologies required for LBGs. Schools and educators must address this disparity to ensure that all students can benefit from these innovative learning experiences (Bengel & Peter, 2021; Barab et al., 2007).

This study highlights the significant potential of location-based games to enhance environmental literacy and engagement in biology education. By leveraging the interactive and immersive capabilities of LBGs, educators can create meaningful and effective learning experiences that connect students with the real-world implications of their studies. As education continues to evolve, LBGs represent a powerful tool for enriching biology education and fostering a generation of environmentally literate and engaged students. The future of education lies in harnessing these innovative technologies to create more engaging, relevant, and impactful learning experiences.

Recommendations

To overcome these challenges and maximize the benefits of LBGs, several steps are recommended:

- **Strategic Integration:** Educators should integrate LBGs into the curriculum thoughtfully, ensuring they enhance rather than complicate the learning process. This includes aligning game content with educational objectives and providing support for teachers in game facilitation (Bengel & Peter, 2021).
- **Professional Development:** Teachers should receive training on how to effectively use LBGs in their teaching. This training should cover both the technical aspects of these games and strategies for integrating them into educational practices (Barab & Dede, 2007).
- **Research and Evaluation:** Continued research is essential to explore the long-term impacts of LBGs on environmental literacy and to refine these tools for greater effectiveness. Empirical studies can provide deeper insights into how these games influence learning outcomes and student attitudes (National Research Council, 2009; Schaal et al., 2018).
- **Collaborative Efforts:** Schools and educators should collaborate to share resources and best practices for using LBGs. By pooling knowledge and experiences, the educational community can collectively improve the use of these innovative tools (Klopfer et al., 2009).

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