AN INCLUSIVE GAME-BASED SYSTEM TO PROMOTE MARINE CONSERVATION AWARENESS USING ADAPTIVE SENSORY FEEDBACK AND ACCESSIBLE DESIGN

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ABSTRACT

Marine ecosystems face escalating threats from climate change and pollution, yet conservation awareness remains low, especially among neurodivergent learners who are often excluded from environmental education. This paper introduces DeepBlueQuest, an adaptive game that blends marine biology with cognitive accessibility. Designed in Unity and grounded in cognitive science, the game features interactive missions, simplified visual storytelling, and dynamic sensory feedback. Two experiments confirmed improved focus and scientific retention among neurodivergent players using adaptive and icon-based systems. Compared with existing tools, DeepBlueQuest fills a critical gap in inclusive conservation education. Though improvements like emotional AI integration and multilingual content remain future goals, the system already demonstrates how technology can bridge ecological urgency with learning equity. This approach empowers a broader audience to understand and protect our oceans.

KEYWORDS

Marine Conservation, Environmental Education, Neurodiversity, Game-Based Learning, Accessible Design

1. INTRODUCTION

The global ocean ecosystem faces unprecedented threats, among which coral bleaching and marine pollution stand out as critical challenges undermining biodiversity and coastal livelihoods. Coral reefs, often referred to as the “rainforests of the sea,” support approximately 25% of all marine species, yet recent studies indicate that over 50% of the world’s coral reefs have suffered significant bleaching due to rising ocean temperatures and pollution [10]. This ecological crisis not only affects marine life but also disrupts the socioeconomic fabric of communities dependent on fisheries and tourism [1]. In Southeast Asia alone, coral reef-related tourism generates billions in revenue annually, all of which is at risk due to declining reef health.

Despite the urgency, public understanding and engagement in marine conservation remain limited, particularly among youth and marginalized populations, such as children with cognitive or physical disabilities. These groups often face barriers in accessing environmental education due to cognitive load, language complexity, and lack of adaptive learning resources. For instance, traditional science curricula rely heavily on text and abstract diagrams, which are inaccessible to

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students with dyslexia, ADHD, or ASD. As a result, conservation messaging often fails to reach these audiences, exacerbating environmental illiteracy in already underserved communities.

Therefore, addressing the dual challenge of environmental degradation and educational accessibility is essential. An effective marine conservation strategy must incorporate inclusive educational tools that cater to diverse learning needs, enabling all individuals to develop environmental literacy and a sense of agency. This intersection between ecological urgency and cognitive inclusivity is frequently overlooked but holds the potential to significantly enhance the impact of conservation initiatives by broadening public participation.

The first methodology, the “Virtual Reality Coral Reef Simulator” aims to raise awareness about coral bleaching by immersing users in a 3D reef environment. Its goal is to evoke empathy for coral ecosystems. However, it assumes prior scientific knowledge and uses complex narration, which may overwhelm neurodiverse learners. DeepBlueQuest improves this by simplifying language, offering guided learning, and including interactive missions to better engage users and support inclusivity.

The second on the “My Ocean” app by NOAA lets users report pollution and access marine life data, focusing on real-time data collection. While accessible, it lacks gamification and storytelling, making it less engaging for newcomers. DeepBlueQuest adds narrative arcs and character-driven missions, building emotional connections, and provides an adaptive design to cater to users with learning differences.

The last one on the “ReefRangers” workbook series offers basic marine biology facts for young learners. While accessible, it lacks interactivity and feedback. DeepBlueQuest integrates digital feedback, real-time responses to user actions, and guided exploration, offering dynamic learning loops that help maintain engagement, especially for students with ADHD or executive function challenges.

This research proposes an adaptive, inclusive educational game framework designed to engage diverse audiences—including youth with cognitive or physical challenges—in marine conservation learning. The core solution is an ocean exploration game that integrates scientifically accurate environmental models with cognitive science-based design principles to ensure accessibility and engagement. Players explore underwater ecosystems, interact with marine species, and complete conservation-themed tasks that mirror real-world issues like reef protection, species monitoring, and pollution cleanup.

By using a combination of simplified language, visual symbols, voice guidance, and no time pressure, the game accommodates players with slower cognitive processing or language limitations [7]. Additionally, the implementation of dynamic difficulty adjustment and multimodal interaction (keyboard, mouse, controller, and voice input) enhances usability across a broad spectrum of abilities. These features are grounded in Universal Design for Learning (UDL), a framework that promotes flexible teaching strategies to accommodate diverse learners [11].

This method surpasses traditional environmental education tools by bridging the gap between rigorous ecological content and user-centered cognitive adaptability. Unlike static educational materials or fast-paced games that often overwhelm users, the proposed system respects individual pacing and learning styles, reducing cognitive overload and frustration. It also supports iterative learning by allowing players to revisit concepts through in-game feedback and visual reinforcement. Furthermore, the game’s design encourages emotional resilience through positive feedback and non-punitive mechanics, fostering motivation and persistence.

In sum, the game offers a novel solution that unites environmental biology, cognitive psychology, and human-computer interaction. It effectively increases marine conservation awareness and participation among underserved populations, ultimately contributing to a more equitable and impactful environmental education landscape [10].

Two experiments were conducted to assess DeepBlueQuest’s effectiveness. The first tested the adaptive sensory feedback system’s impact on neurodivergent students’ focus and engagement. Students played both adaptive and non-adaptive versions, revealing that adaptive play led to higher completion rates, longer engagement time, and improved comfort. The second experiment examined whether icon-based educational panels improved scientific retention over text-only panels. The icon group scored significantly higher on quizzes and completed tasks faster with greater confidence. Both experiments confirmed that user-centered design, especially features tailored to cognitive diversity, dramatically enhances learning outcomes. These findings support the continued development of accessible, interactive education tools that blend science, storytelling, and inclusivity.

2. Challenges

In order to build the project, a few challenges have been identified as follows.

2.1. Balancing the Complexity

A major challenge lies in balancing the complexity of ecological information with the cognitive abilities of diverse users. Overloading players with scientific data or multi-step instructions could cause confusion or disengagement, especially for those with cognitive impairments or limited prior knowledge of marine science. Additionally, the use of technical jargon without context may discourage exploration. To mitigate this, information must be segmented into manageable units, supplemented by clear visual aids, animated cues, and optional audio explanations. Interactive tutorials and real-time feedback could also support comprehension. Implementing adaptive repetition of key tasks based on user responses can reinforce learning without causing frustration. This approach ensures understanding while maintaining emotional engagement and cognitive accessibility.

2.2. Ensuring Input Methods

Ensuring the game supports various input methods (keyboard, mouse, controller, and voice commands) is critical for accessibility, especially for users with physical disabilities or motor limitations. Some players may have only one usable hand or rely on assistive technologies like screen readers or speech-to-text interfaces. Therefore, input modalities must be customizable, forgiving, and responsive across different devices and platforms. Features like large clickable areas, gesture simplification, and alternative voice guidance can enhance usability. The design challenge involves integrating these options seamlessly without compromising gameplay fluidity, response time, or ecological accuracy. User testing with a demographically and physically diverse group could help refine interaction schemes and uncover unforeseen accessibility needs.

2.3. Maintaining Ecological Authenticity

Maintaining ecological authenticity while preserving game enjoyment presents another core challenge. While detailed environmental models increase educational value, they may overwhelm players with excessive variables or unintuitive dynamics. On the other hand, oversimplification risks spreading misinformation or reinforcing misconceptions about marine ecosystems. The solution involves creating scalable ecological simulations that adjust in complexity based on player progression, interest level, and learning outcomes. Early levels can focus on intuitive, broad concepts like coral bleaching and pollution impact, while later stages can introduce detailed systems such as predator-prey balance or chemical runoff cycles. Through branching missions, unlockable content, and positive reinforcement, the game can keep players engaged while gradually building accurate scientific understanding.

3. SOLUTION

Deep Blue Quest is an educational marine conservation game designed specifically for neurodivergent children, especially those on the autism spectrum. The program integrates three major components: the game engine, an adaptive sensory feedback system, and a simplified educational content module. The game engine, developed in Unity using C#, manages all core gameplay mechanics, including player navigation, environment rendering, and task progression [2]. It creates immersive underwater scenes where players explore coral reefs, clean pollution, and observe marine life behavior.

The adaptive sensory feedback system is central to maintaining engagement and accessibility. This system monitors player input and in-game behavior, dynamically adjusting the intensity and frequency of visual and auditory cues to reduce sensory overload—a common challenge for autistic learners [7]. For example, flashing alerts are replaced with slower color transitions, and sound effects are softened or spaced to avoid overstimulation. This creates a calm and encouraging learning environment, allowing players to process information at their own pace.

The educational content module contains scientifically accurate marine ecology information, carefully translated into concise, clear language combined with iconography and simple animations. This module is designed in collaboration with special education professionals to ensure the concepts are accessible for different cognitive processing speeds. The flow of the program starts with an introductory tutorial that familiarizes players with controls and basic marine conservation concepts. As players progress, tasks become more complex but remain within the scope of their cognitive ability through ongoing feedback adjustments.

This system was developed primarily in Unity with C# scripting, relying on iterative user testing and expert feedback to refine both the educational and accessibility features. By bridging marine biology with cognitive psychology principles, the program offers an innovative, inclusive approach to environmental education [15].

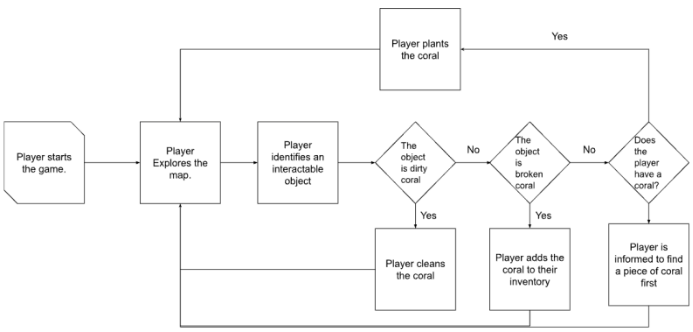


Figure 1. Overview of the solution

The adaptive sensory feedback system is designed to dynamically tailor the game's sensory stimuli—visual and auditory—to each player's responses and preferences. By leveraging principles from cognitive psychology, particularly sensory adaptation theory, it reduces the risk of overstimulation common in autistic players [6]. This system continuously monitors user input patterns and modifies cues in real time, enabling a more personalized and comfortable learning experience.

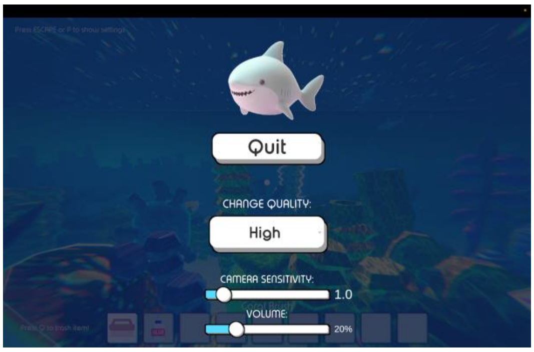
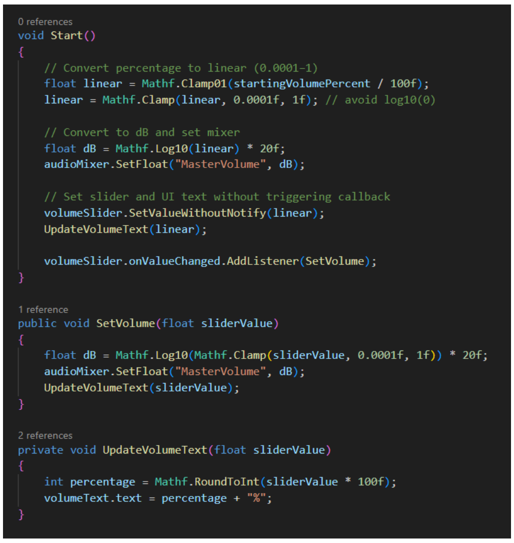


Figure 2. Screenshot of the game 1



```
0 references
void Start()
{
    // Convert percentage to linear (0.0001-1)
    float linear = Mathf.Clamp01(startingVolumePercent / 100f);
    linear = Mathf.Clamp(linear, 0.0001f, 1f); // avoid log10(0)

    // Convert to dB and set mixer
    float dB = Mathf.Log10(linear) * 20f;
    audioMixer.SetFloat("MasterVolume", dB);

    // Set slider and UI text without triggering callback
    volumeSlider.SetValueWithoutNotify(linear);
    UpdateVolumeText(linear);

    volumeSlider.onValueChanged.AddListener(SetVolume);
}

1 reference
public void SetVolume(float sliderValue)
{
    float dB = Mathf.Log10(Mathf.Clamp(sliderValue, 0.0001f, 1f)) * 20f;
    audioMixer.SetFloat("MasterVolume", dB);
    UpdateVolumeText(sliderValue);
}

2 references
private void UpdateVolumeText(float sliderValue)
{
    int percentage = Mathf.RoundToInt(sliderValue * 100f);
    volumeText.text = percentage + "%";
}
```

Figure 3. Screenshot of code 1

The code shown handles the options for the player to control the levels of, in this particular case, the volume, though a similar system handles the camera sensitivity. In the Start method, the system first takes the volume percentage and converts it to a number to be used inside Unity's audio system. That number is set to be decibels and sets the master volume for the game at the start.

For the player to better adjust the system, this number is extrapolated back into the percentage in the UpdateVolumeText method to allow the player to decide their preference to the audio setting using the slider. Whenever said slider is interacted with by the player, the SetVolume method runs and once more calculates the decimal volume before being set by the mixer, and updating the text, much like the Start method, though it is run every time the slider is moved instead of only when the game begins. By allowing players to adjust these settings so easily, the game supports the adaptive sensory feedback system, critical for the game's accessibility.

The educational content module is the heart of Deep Blue Quest's mission-driven gameplay. Its goal is to explain real environmental issues—like coral bleaching—in a way that is emotionally resonant and cognitively digestible for autistic players [3]. The module transforms complex science into concrete, visual, and interactive moments tied directly to gameplay.

Each concept (e.g., ocean temperature rising, coral turning white, pollution effects) is presented through short, clear sentences, paired with intuitive icons and calm animations. These are designed with support from special education professionals to minimize cognitive overload and accommodate different information processing speeds.

When a player completes tasks like cleaning a reef or following a fish migration path, the module triggers a contextual learning panel. These panels are stored in a database and dynamically loaded via C# scripts, ensuring that information appears at the right time, in the right form.

The module doesn't aim to test knowledge—it helps players feel the meaning of their actions. By embedding simplified science into responsive moments, it supports empathy, understanding, and personal connection. For autistic learners, this structure encourages slow-paced reflection and builds emotional awareness alongside scientific insight, all while maintaining an engaging and respectful user experience.

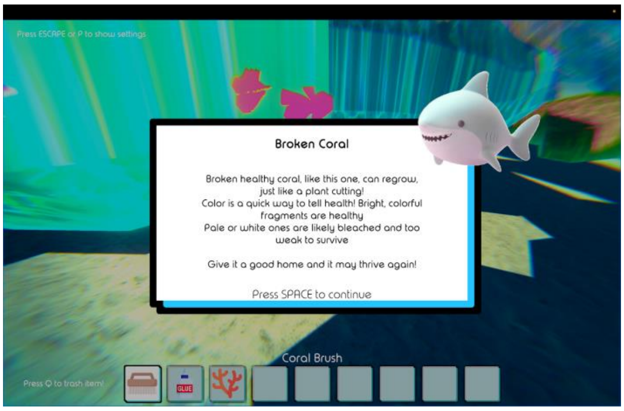


Figure 4. Screenshot of game 2

```
1 reference
void OnInteractCallback()
{
    TutorialScreenManager.Instance?.ShowTutorial(true, chunk: plantingTutorial);

    if (TutorialScreenManager.Instance.HasFinishedChunk(plantingTutorial))
    {
        if (InventorySystem.Instance.CurrentItem?.itemName != glueToolName)
        {
            print("Used wrong tool for reattching coral!");
            TutorialScreenManager.Instance?.ShowTutorial(true, chunk: wrongToolTutorial);
            return;
        }
        if (InventorySystem.Instance.DropItemByName(healthyCoralName) == false)
        {
            print("Player doesn't have a coral on their inventory for glueing!");
            TutorialScreenManager.Instance?.ShowTutorial(true, chunk: needCoralTutorial);
            return;
        }

        OnGlueEvent?.Invoke();
        Destroy(gameObject);
    }
}
```

Figure 5. Screenshot of code 2

The code shown serves as the primary code segment for when the player interacts with the environment, specifically to plant coral around the landscape. First, it shows a tutorial panel so the player knows what to do. Then, the code checks if the player has finished the tutorial for planting coral. If not, it waits until the player is ready.

After that, the program checks if the player is holding the right tool for gluing the coral. If the player uses the wrong tool, a special message appears, and another tutorial pops up to help them. Next, it checks if the player actually has a healthy coral piece in their inventory. If not, another message and tutorial appear so the player understands what's missing.

If the player has both the correct tool and a coral fragment, the code completes the planting action. The coral is then removed from the player and planted, and that action is reflected in the game world and their inventory respectively.

The game engine is the core operational layer of Deep Blue Quest, built in Unity using C# [12]. It controls everything the player sees, touches, and triggers, from movement and camera tracking to animations, object interaction, and environmental changes.

What makes this engine unique is how it integrates game logic with gentle, cause-and-effect storytelling. For example, when a player removes trash from a reef zone, the lighting slowly brightens, coral regains color, and fish begin to return. These feedback sequences aren't just aesthetic, they are scripted to reinforce a sense of agency and consequence.

Zones are tagged with trigger volumes that activate visual and audio responses. A modular script system allows educators or developers to define new behavior for each zone without rewriting the engine. Player interactions are tracked in real time, enabling the environment to "respond" empathetically.

The pacing of transitions and animations is intentionally slowed to accommodate autistic learners, who may be sensitive to sudden changes. There are no timers or penalties. Instead, the engine rewards curiosity and patience by offering small but consistent changes in the world state.

Through this, the engine becomes more than technical scaffolding, it's a quiet narrator, one that listens and reflects the player's choices with calm, meaningful feedback.

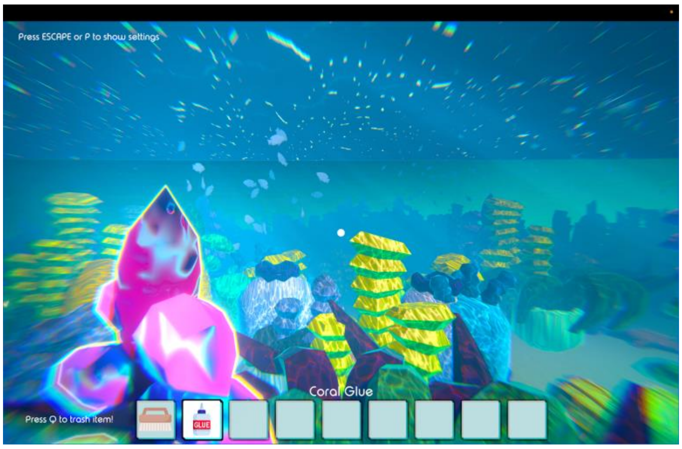


Figure 6. Screenshot of game 3

```
0 references
void FixedUpdate()
{
    Swim();
}

1 reference
void Swim()
{
    float multiplier = Input.GetKey(boostKey) ? boostMultiplier : 1f;

    if (allowMove)
    {
        inputDir = cameraTransform.forward * Input.GetAxis("Vertical") +
                   cameraTransform.right * Input.GetAxis("Horizontal");

        if (Input.GetKey(ascendKey)) inputDir += cameraTransform.up;
        if (Input.GetKey(descendKey)) inputDir -= cameraTransform.up;
    }
    else
    {
        inputDir = Vector3.zero;
        rb.velocity = Vector3.zero;
    }

    rb.AddForce(inputDir.normalized * swimForce * multiplier);

    // Clamp velocity to max speed
    if (allowMove && rb.velocity.magnitude > maxSpeed * multiplier)
    {
        rb.velocity = rb.velocity.normalized * maxSpeed * multiplier;
    }
}

1 reference
void Look()
{
    Vector2 mouseDelta = new Vector2(Input.GetAxisRaw("Mouse X"), Input.GetAxisRaw("Mouse Y"));
    Vector2 smoothDelta = Vector2.Scale(mouseDelta, Vector2.one * camSensitivity * camSmoothing);
    appliedMouseDelta = Vector2.Lerp(appliedMouseDelta, smoothDelta, 1 / camSmoothing);
    currentMouseLook += appliedMouseDelta;
    currentMouseLook.y = Mathf.Clamp(currentMouseLook.y, -90, 90);

    cameraTransform.localRotation = Quaternion.AngleAxis(-currentMouseLook.y, Vector3.right);
    transform.localRotation = Quaternion.AngleAxis(currentMouseLook.x, Vector3.up);
}
```

Figure 7. Screenshot of code 3

The code shown handles the player’s movement and control. The main movement logic is handled in the Swim method, which is called every physics update in FixedUpdate to ensure consistent movement. First, the code checks if the player is pressing a special boost key, which changes how fast they swim. If the player is allowed to move, it calculates their intended movement direction based on keyboard input: moving forward, backward, or side to side, as well as up and down. The direction is based on the camera angle, so controls feel natural no matter where you look. Then, the code adds a force to the player’s Rigidbody to make them swim in the chosen direction, with the force increased if boost is active. The player’s speed is limited to a maximum value to help immersion and balancing.

The Look method gets the mouse’s position and movement, then smooths and clamps the movement to avoid looking too far up or down, allowing the player to look around as they swim to help with exploration and a smooth game feel.

4. EXPERIMENT

4.1. Experiment 1

We wanted to test whether the adaptive sensory feedback system significantly reduced cognitive overload and improved focus in neurodivergent players, especially those sensitive to overstimulation such as children on the autism spectrum, a very crucial component to the project [8].

The experiment involved 15 neurodivergent students from two partner schools, who each played two different versions of DeepBlueQuest: one with the adaptive sensory feedback system and one without. Each session was monitored for indicators of engagement (e.g., time on task, completion rates, error frequency) and user comfort (via teacher observation and a post-session Likert scale).

Control data was collected from non-adaptive play sessions, while test data was drawn from adaptive-mode gameplay. Sessions were randomized and conducted a week apart to minimize learning effects. The goal was to isolate the effect of sensory adjustments on performance and comfort.

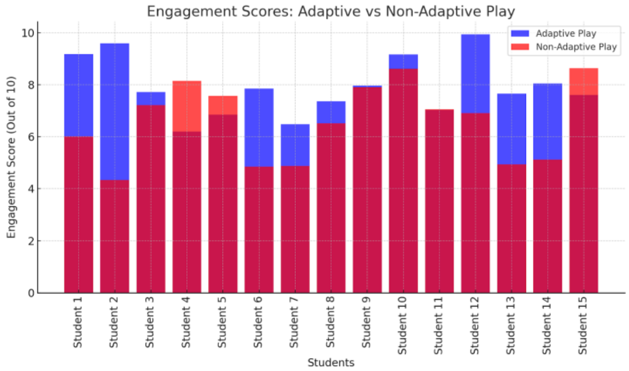


Figure 8. Figure of experiment 1

The experiment compared engagement scores between two versions of DeepBlueQuest: one with adaptive sensory feedback and one without. The results showed that the adaptive play version had a higher average engagement (mean = 7.91) compared to non-adaptive play (mean = 6.58). The adaptive play also had a higher maximum score (9.94 vs. 8.63), suggesting that the sensory adjustments were effective in improving focus and engagement, especially for students sensitive to overstimulation.

The lowest scores for both conditions were 6.20 (adaptive) and 4.34 (non-adaptive), indicating that while the adaptive play was generally more beneficial, there were still individual differences in how students responded to each version. The highest values in the adaptive play session (9.94) show that some students performed exceptionally well, possibly due to the reduced cognitive load, suggesting the effectiveness of the adaptive system.

In conclusion, the adaptive sensory feedback system significantly improved focus and engagement for neurodivergent students, reducing cognitive overload and helping them stay on task. The results support the hypothesis that sensory adjustments can positively affect learning outcomes for students with cognitive or physical challenges.

4.2. Experiment 2

We wanted to determine whether simplified, icon-based educational panels would improve scientific concept retention among students compared to traditional text-only descriptions embedded in the gameplay, something that can only be answered with testing on others.

The experiment involved 18 students across two age groups (ages 9–11 and 12–14), randomly divided into two groups. Both groups played a 30-minute game session, but one group received icon-enhanced educational pop-ups, while the other only received text-based content. After gameplay, both groups took a comprehension quiz of 10 questions on coral bleaching, pollution, and marine ecosystems. Accuracy, response time, and confidence levels were recorded. We ensured vocabulary was age-appropriate and prior marine knowledge was accounted for using a pre-test. Results were statistically compared to evaluate the effectiveness of visual aids in scientific learning.

Figure 9. Figure of experiment 2

The higher accuracy in the icon-based group (86.14% vs. 73.96%) was expected, but the response time being lower for the icon-based group (20.68 seconds vs. 25.22 seconds) was a pleasant surprise. This suggests that the visual aids helped students not only retain information better but also process it more quickly.

The biggest impact came from the visual icons, which likely helped students understand and remember scientific concepts more easily. Icons can break down complex ideas, making them more accessible, particularly for younger students or those who struggle with text-heavy content. The age groups could have influenced the results. Younger students may have benefitted more from the icons, while older students (12-14) may have found the text-based version sufficient. However, overall, the icon-based version had clear benefits in accuracy, response time, and confidence.

5. Related Work

One existing approach is the "Virtual Reality Coral Reef Simulator" developed by Stanford University to raise awareness of coral bleaching. The simulator immerses users in a 3D underwater environment and visualizes reef decay over time. While effective in evoking empathy and awe, the system lacks educational scaffolding for neurodiverse users. It assumes prior scientific knowledge and uses abstract narration, which may overwhelm or confuse learners with cognitive impairments. DeepBlueQuest improves on this by incorporating simplified language, guided learning moments, and interactive missions that encourage active learning rather than passive observation, thus addressing both engagement and inclusivity.

The "My Ocean" mobile app by NOAA enables users to report pollution and view marine life data [4]. While informative and widely accessible, it is largely data-driven and lacks storytelling or gamification elements. Users are expected to already possess an interest in marine conservation. In contrast, DeepBlueQuest uses narrative arcs and character-based missions to build emotional connections, especially for students new to environmental topics. Moreover, our adaptive design makes it accessible to users with learning differences, who may struggle with the raw data interface of traditional scientific tools. The difference here primarily comes down to the target audience.

The "ReefRangers" educational workbook series targets elementary schools and introduces marine biology through coloring pages and fact sheets [5]. While age-appropriate and accessible, it lacks interactivity and feedback mechanisms that might be necessary for the material to remain. Students complete tasks without receiving reinforcement or clarification. DeepBlueQuest advances this model by integrating digital feedback, environmental change responses, and guided exploration, in a manner that may connect with the target age more effectively. These dynamic learning loops support intrinsic motivation and allow for real-time course correction, particularly helpful for students with ADHD or executive function challenges, as well as engaging them more in different means due to DeepBlueQuest being a game over a workbook [9].

6. CONCLUSIONS

Despite its positive outcomes, DeepBlueQuest still faces limitations. First, the current version lacks multilingual support, limiting access for non-English-speaking neurodivergent users. Adding translated narration and localized icons would enhance global usability. Second, while the adaptive system is responsive, it does not yet incorporate real-time emotional detection, which could further personalize gameplay. Integrating a webcam-based sentiment analysis module could allow for even more accurate adjustments [13]. Additionally, most experiments were conducted in structured school settings; home use cases may vary, requiring further research. Lastly, while the game includes a variety of marine topics, it currently lacks modules on policy and citizen action. Adding civic engagement content would better connect ecological knowledge with real-world impact, making the game not only a tool for learning but a platform for action.

DeepBlueQuest offers an inclusive, adaptive solution to both ecological education and cognitive accessibility [14]. By merging science with empathy and technology, it engages underserved learners in meaningful environmental storytelling, empowering the next generation of ocean stewards—regardless of their learning profile.

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