Engaging Primary School Children in Environmental Education Through Citizen Science

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Thesis

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science is entirely my own work, and that I have exercised reasonable care to ensure that the work is original and have conformed to the regulations on the use of and declaration of Generative AI, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Abstract

This dissertation examines approaches to supporting Environmental Education (EE) by engaging primary school pupils in Citizen Science (CS) focused on freshwater conservation. In response to the decline in water quality in Ireland, the study compares two methods: a traditional paper-based approach and a digital approach using a mobile app designed to assist with macroinvertebrate-based water quality monitoring. The research explores how these approaches influence pupils' engagement and self-efficacy in participating in CS. A quasi-experimental study was carried out in three Irish primary schools, with experimental groups using the app and control groups using paper-based methods. The workshops combined classroom learning with practical activities involving the identification of live macroinvertebrates, enabling pupils to explore their local ecosystems as citizen scientists. Quantitative data were collected on perceived usefulness, ease of use, enjoyment, and behavioural intention, along with adapted measures of scientific self-efficacy. Findings suggest that both approaches promoted engagement and learning. The digital tool showed modest advantages in usability and perceived learning, while the traditional method was associated with a stronger intention to reuse and share the experience. Across both groups, students demonstrated increased confidence in scientific tasks such as identifying, counting, and recording macroinvertebrates. These outcomes indicate that digital tools can complement traditional methods, supporting blended approaches that combine interactivity with collaboration and reflection. This study contributes to research in EE, CS, and educational technology by providing empirical insights into the role of mobile tools in primary education for environmental stewardship. It emphasises the value of involving children as active participants in scientific enquiry and highlights the potential of such initiatives to foster environmental and data literacy. Recommendations are made for the design of digital tools with emotional, collaborative, and linguistic supports, and for the future development of EE through longitudinal and cross-contextual research.

List of Presentations

Pioneering Environmental Education: Pilot Study of the AquaInverts App for Primary School Children as Citizen Scientists. Poster presented at DKIT Research Day, Dundalk, Ireland, May 2024.

Together for a Better Future: DKIT's Sustainable Development Goals Workshop. Poster presented at NTUTTOR Showcase, Dublin, Ireland, April 2024.

Engaging Children in Environmental Education Through Citizen Science: App vs. Paper. Poster to be presented at the Children and Nature Conference 2025, Minneapolis–Saint Paul, USA.

List of Abbreviations

BI	Behavioural Intention
CS	Citizen Science
CSSES	Citizen Science Self-Efficacy Scale
CSSI	Citizen Science Stream Index
EE	Environmental Education
ESD	Education for Sustainable Development
IPCC	Panel on Climate Change
IUCN	International Union for Conservation of Nature
LAWPRO	Local Authority Water Programme
ORCCA	Oriel River Catchment and Coastal Association
PE	Perceived Enjoyment
PU	Perceived Usefulness PEoU - Perceived Ease of Use
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
EPA	Environmental Protection Agency
WFD	Water Framework Directive EU - European Union
WIAT	Woods In and Around Towns
WM	World Meteorological Organisation

Chapter 1

Introduction

Climate Change, Water Quality, and the Role of Education

The impacts of environmental crises are affecting more people and places than ever before. According to the World Meteorological Organization (WMO), the consequences of climate change intensified globally in 2024, spreading from mountain peaks to ocean depths and affecting communities, economies, and ecosystems (WMO, 2024, para. 1). The Intergovernmental Panel on Climate Change (IPCC) has confirmed the increasing extent and impact of anthropogenic climate change on a planetary scale. In its Sixth Assessment Report (IPCC, 2023), it highlighted that human-induced climate change has already caused widespread and severe impacts, disproportionately affecting vulnerable communities. It is argued that climate change is not unique to our era and has been a natural component of Earth's climatic system for millions of years (Muruganandam, M. et al., 2023). However, human activities over the past centuries have accelerated and intensified these changes at an unprecedented rate, fundamentally altering natural cycles. In particular, climate change has disrupted the Earth's water cycle, leading to more frequent and severe droughts and floods.

In 2024, extreme weather events caused catastrophic human and economic losses, resulting in at least 8,700 deaths and over $550 billion in damages (Carrington, 2025). As climate change continues to reshape ecosystems and communities worldwide, its effects are particularly pronounced in the lives of younger generations. In response to these growing environmental problems, education, particularly Environmental Education (EE), is increasingly regarded as a crucial instrument to foster sustainability. EE equips future generations with scientific knowledge and environmental consciousness, allowing students to participate in conservation activities and generate informed solutions to critical ecological concerns.

EE has been increasingly recognised as one of the most critical tools for driving the transformation towards sustainability (Trott, 2020; Busch, Henderson, & Stevenson, 2018). In this dissertation, EE is understood in line with the UNESCO-UNEP International Environmental Education Programme (UNESCO, 1978, p. 25), as a reorientation of education that supports informed action on environmental problems. Developing environmental literacy, particularly among younger generations, is key to fostering informed decision-making and proactive conservation efforts. In this context, understanding the ecological significance of

river systems and the urgent need for their conservation is crucial. This study seeks to investigate how digital tools, such as Educational Apps, can enhance EE and scientific literacy among primary school children. By integrating a mobile app called AquaInverts into an EE workshop, this research aimed to assess whether interactive and hands-on learning experiences improve students' engagement with freshwater conservation efforts. Specifically, this research investigates the extent to which using the AquaInverts App to identify macroinvertebrates as bioindicators of water quality fosters scientific literacy and strengthens students' sense of environmental stewardship.

One of the key aims of EE, particularly in programmes focused on freshwater ecosystems, is to educate individuals about the critical role of river systems in maintaining biodiversity, ensuring water quality, and providing ecological connectivity (Arboleya et al., 2021). All living organisms depend on their natural environment, either directly or indirectly, for growth, nutrition, and development, making the health of freshwater ecosystems essential for sustaining life on Earth.

However, the urgency of EE extends beyond ecological understanding. As Richard Louv (2005), a key figure in EE for children, argues in *Last Child in the Woods*, the environmental crises we face are closely linked to what he calls *"nature-deficit disorder"*, the growing disconnection between children and the natural world. This disconnection Louv suggests, carries profound consequences not only for the environment, but also for the psychological, emotional, and social development of young people. He warns that "care for nature increasingly becomes an intellectual concept, severed from the joyful (youthful) experience of the outdoors" (p. 147), and reminds us that "passion is lifted from the earth itself by the muddy hands of the young" (p. 159).

In light of these concerns, EE must do more than simply transmit scientific facts: It must create opportunities for children to reconnect with nature in ways that are sensory, experiential, and emotionally meaningful. This research explores one possible pathway to that reconnection by combining digital technology with outdoor ecological engagement. By inviting children to explore their local ecosystems to identify macroinvertebrates, this study investigates how interactive learning experiences can foster both scientific literacy and a renewed sense of environmental belonging.

Water Quality Monitoring

Traditional water quality assessments rely heavily on chemical and physical measurements, such as nutrient levels, pH, and dissolved oxygen concentrations. However,

these snapshots of water conditions can be limited in their ability to reflect long-term ecological health (Holt & Miller, 2011). To complement these methods, biological indicators, or bioindicators, have become an essential tool in environmental monitoring. These include various organisms that respond predictably to changes in water quality, making them reliable indicators of ecosystem health (EPA, 2024; McSorley, 2022). Among these, aquatic macroinvertebrates, small animals without backbones that live in freshwater habitats, are widely used as bioindicators in river health assessments due to their sensitivity to pollution, ease of collection, and well-documented ecological roles (Holt & Miller, 2011; Blake & Rhanor, 2020).

Macroinvertebrates inhabit nearly all freshwater ecosystems around the world, even those that initially appear to be uninhabitable. As fundamental components of freshwater systems, they sustain the food web in that they supply food to a wide range of different organisms (Michaluk, 2019; McSorley, 2022). They also facilitate decomposition of live and dead vegetation in freshwater systems to allow organic matter to be transformed to energy that sustains other freshwater organisms (Callisto et al., 2001; McSorley, 2022).

Macroinvertebrates are one of the most universally applied biological indicators of water quality, a widely applied method in scientific investigations across the globe. The use of such organisms in biomonitoring is not new, as there is evidence that Aristotle mentioned it as far back as 350 BC (Moog et al., 2018; McSorley, 2022). This research examines how primary school children in Ireland engage with a workshop to assess river water quality. By integrating Educational Technology (App) into EE and Science Outreach Programmes, this study explores whether and how digital technology enhances children's scientific literacy, environmental awareness, and engagement in freshwater conservation.

About the App

Through the app, students can participate in local water quality monitoring projects by collecting and identifying macroinvertebrates in rivers and streams. This hands-on experience provides children with essential skills in observation, data collection, and critical thinking, allowing them to witness firsthand how scientific research is conducted. Since different species have varying levels of tolerance to pollutants, children can assess the health of their local water bodies based on the presence or absence of certain macroinvertebrates. This process makes environmental science more tangible and helps children understand the direct impact of human activities on water quality. Through this interactive approach, children develop an early awareness of environmental issues, encouraging them to think critically about conservation and

sustainability. Beyond individual learning, the App was also designed to promote collaborative learning in classrooms, enabling children to work together, compare findings, and share their observations. By integrating education, technology, and real-world application, it fosters scientific literacy and strengthens students' sense of environmental stewardship.

The main research question guiding this study is:

How can an educational app support primary school children's engagement and scientific self-efficacy in a citizen science-based environmental education workshop?

To explore this overarching question, the following sub-questions are investigated:

1. How do children perceive and interact with a mobile app designed for environmental education in a workshop setting, and how does their engagement compare to those using a traditional paper-based method?

2. How do children perceive their ability to contribute reliable scientific information as citizen scientists, and does this perception differ between those using the AquaInverts mobile app and those using traditional paper-based methods?

Specifically, it investigates the effectiveness of the educational App in fostering environmental awareness and knowledge retention about macroinvertebrates as bioindicators of water quality. The research aims to evaluate students' perceptions of the app in terms of usability, engagement, and learning experience. It assesses the key factors influencing their interaction with the platform, such as enjoyment and intention to use. Additionally, the study examined whether the app improves students' confidence in scientific data collection and their ability to contribute to environmental monitoring initiatives. By comparing the App with traditional paper-based methods, this research sought to determine which approach is more effective for knowledge retention in environmental education. Ultimately, the study evaluates the extent to which digital tools can empower young learners, promote scientific literacy, and encourage active participation in freshwater conservation efforts.

While EE is widely recognised as essential for fostering sustainability, there remains a gap in understanding how digital tools might enhance engagement, scientific literacy, and long-term environmental stewardship among young learners. Existing research primarily focuses on traditional teaching methods, with limited empirical evidence on the effectiveness of mobile applications in primary education for freshwater conservation. Digital technologies, however, may offer an opportunity to transform environmental education by making learning interactive

and engaging.

One of the main gaps is found in Brečka, Valentová, and Tureková's (2022) study. The authors highlight that despite schools having access to innovative didactic tools, there is a lack of interactive software and structured methodological materials to integrate digital learning into EE effectively. Their study found that using Smart Notebook software in primary schools significantly improved student engagement, knowledge retention, and environmental awareness through gamified digital learning experiences. They further emphasise that digital tools, such as interactive whiteboards and multimedia content, can bridge the gap between theoretical knowledge and practical environmental responsibility by allowing students to visualise ecological phenomena and actively participate in sustainability practices.

While previous studies highlight the effectiveness of EE in fostering sustainability (Trott, 2020; Busch et al., 2018), there is limited empirical research on how mobile apps might seek to enhance children's engagement with freshwater conservation. This study seeks to address that gap by examining the App as an educational intervention.

Environmental Education as Transformative

Since the 1970s, the United Nations has addressed EE as a solution to environmental crises, bringing global attention to the issue through international conferences (United Nations, 1972; United Nations, 1993; United Nations, 2012; United Nations, 2015). Here, we understand EE as defined by the UNESCO-UNEP International Environmental Education Programme (1978), which describes it as: "*The result of the reorientation and dovetailing of different disciplines and educational experiences which facilitate an integrated perception of the problems of the environment, enabling more rational action, capable of meeting social needs, to be taken*" (UNESCO, 1978, p. 25). Although this definition was established almost five decades ago, it remains highly relevant today, particularly as global environmental crises demand not only knowledge but also active engagement and systemic change.

According to the UNESCO (1978) report, EE has three main objectives:

> *a) To foster clear awareness of, and concern about, economic, social, political, and ecological interdependence in both urban and rural areas.*
>
> *b) To provide every person with opportunities to acquire the knowledge, values, attitudes, commitment, and skills needed to protect and improve the environment.*
>
> *c) To create new patterns of behaviour among individuals, groups, and society as a whole towards the environment (UNESCO, 1978, p. 26)*

While the foundational principles of EE have been emphasised since the 1970s and have been the focus of numerous international conferences involving policymakers from different parts of the world, the field has advanced significantly over the past decades, building upon the framework outlined by UNESCO (1978). Researchers have developed various theoretical frameworks (Mezirow, 1991; Mayer & Frantz, 2004; Gruenewald, 2003; Vohland et al., 2021; Rickinson & McKenzie, 2020; Ruiz-Mallén et al., 2022; Kuthe et al., 2019; Souza, Williams & McEwen, 2021; Fauville et al., 2021) to enhance the effectiveness of EE, incorporating interdisciplinary approaches from education, psychology, and environmental sciences.

A comprehensive review of the literature highlights several theoretical frameworks that shape EE, including Transformative Learning, Environmental Literacy, Critical Pedagogy and Eco-Pedagogy, Place-Based and Relational Pedagogies, Imaginative Ecological Education, Connectedness to Nature and Pro-Environmental Behaviour, and the Whole School Approach. These frameworks address key questions such as how people develop environmental awareness, what motivates pro-environmental behaviour, and how education can foster long-term engagement with sustainability. The sections that follow highlight some pioneering contributions that inform this literature review.

Environmental Education Research

One of the pioneering perspectives that has significantly shaped EE research and practice is Transformative Learning Theory, first introduced in Mezirow's work in the 1970s on perspective transformation. Mezirow (1997) distinguishes between two key domains of learning: instrumental and communicative. Instrumental learning is task-oriented, focusing on improving performance and developing effective means to achieve specific goals. In contrast, communicative learning involves understanding the perspectives, values, and intentions of others, fostering deeper reflection and dialogue. The ultimate goal of transformative learning is not merely the acquisition of knowledge, but the ability to critically reflect on one's own assumptions and beliefs, a crucial aspect of EE. In EE, learners, particularly children, need not only to acquire factual knowledge but also, they need to develop agency to apply that knowledge in real-world situations.

According to Mezirow (2000), transformative learning allows people to negotiate and act on their own purposes, values, feelings, and meanings rather than those ones has uncritically assimilated from others, to gain greater control over their life as a socially responsible, clear-

thinking decision-maker. This critical reflection and self-awareness are essential in EE, as it empowers learners to engage more deeply with environmental issues,

fostering a shift towards sustainability-oriented behaviours and systemic change. Educators and practitioners in EE have increasingly adopted Transformative Learning Theory as a framework to move beyond traditional knowledge transmission to foster critical reflection, experiential learning, and active participation in sustainability efforts.

Another significant theoretical contribution to the field over the decades has been Environmental Literacy. Although the term was first coined in the 1960s by the American scholar Charles E. Roth (1968), it has since been widely adopted by researchers worldwide as a core concept in EE. Disinger and Roth (1992) defined Environmental Literacy as an individual's ability to assess environmental conditions, take informed action to address issues, and sustain the functionality of environmental systems. In this sense, educators aim to equip environmentally literate individuals with the knowledge and skills necessary to critically analyse environmental issues, thereby fostering pro-environmental behaviour.

Over the past decades, the concept has evolved and gained prominence not only in academic research, but also in policy discussions. Scholars such as Hollweg et al. (2011) have further refined the definition, breaking it down into four key components: knowledge, skills, affect (emotions and attitudes), and behaviour. More recent studies, including those by Kuthe et al. (2019) and Cincera et al. (2022), have applied the Environmental Literacy framework in empirical research to advance the field. For example, Kuthe et al. (2019) employed the Environmental Literacy framework to categorise different forms of climate change awareness among teenagers in Germany and Austria. Their findings underscore the need for customised educational interventions and longitudinal studies to improve youth engagement with climate change education over time.

Environmental Education and Freshwater Conservation

As the EE field continues to advance, its practical applications are becoming increasingly vital in addressing ecological challenges. One critical area where environmental knowledge, skills, and behaviours are put into practice is in the conservation and management of freshwater ecosystems, particularly rivers. According to UNICEF (n.d.), approximately two-thirds of the global population experiences water scarcity for at least one month each year, and by 2030, global freshwater demand is projected to exceed supply by 40%, exacerbating the already pressing water crisis (World Economic Forum, 2023). Beyond being essential for human survival, river ecosystems play a crucial role in maintaining biodiversity, regulating water cycles, and sustaining natural systems. However, the situation is becoming increasingly

alarming.

While all of the planet's ecosystems are becoming increasingly vulnerable to climate change (Bellard et al., 2012), freshwater systems are uniquely vulnerable. Freshwater systems harbour approximately 6% of all documented species yet constitute just 0.8% of the planet's surface (Dudgeon et al., 2006). This over-representation of biodiversity in freshwater systems coupled with increasing environmental pressures places freshwater organisms and systems at risk across the planet, making conservation in need of urgent action.

In view of river systems playing a key role in sustaining life on the planet, and more specifically our survival, providing a supply of high-quality water to all human beings and organisms is a fundamental aspect of efforts towards conservation of the environment nowadays. Freshwater environments across the world including Ireland, are threatened by human pressures that are compounded by those of climate change. The Environmental Protection Agency's (EPA) report of 2024 raises serious concerns regarding the water quality of the country. Despite having a wide range of systems of water monitoring in place in Ireland, combined with policy mechanisms such as the European Union (EU) Water Framework Directive (WFD), there is evidence of continued challenges in maintaining and improving water quality. This requires a fundamental shift in society's accountability towards the environment.

The EPA (2024) report indicates a range of key challenges regarding Irish water quality in rivers, lakes, estuaries, coastal waters, and groundwater. According to the report, nearly half (46%) of Ireland's surface water fails to meet "good ecological status" in accordance with the EU WFD, with estuary and coastal water quality decreasing dramatically, largely due to nutrient pollution (EPA, 2024). Although government and organisational bodies have sought to address these shortcomings, the report indicates that deterioration continues in other areas. The report attributes decreasing water quality to four principal pressures on Irish water bodies. The most dominant pollutant is agricultural runoff, impacting 1,023 water bodies. The excess of nitrogen and phosphorus in fertiliser and slurry runoff leads to eutrophication, decreasing oxygen levels and killing wildlife predominantly in the south and southeast regions (EPA, 2024).

Another major Irish driver of water quality is urban wastewater pollution, posing a threat to 197 water bodies. Inadequate treatment of wastewater and release of raw sewage deposit pollutants such as organic pollutants, pathogenic organisms, and nutrients in freshwater bodies. Of particular note is that 19 towns and villages continue to release untreated sewage to Irish waters (EPA, 2024). The presence of phosphorus is also exacerbating eutrophication in

rivers, lakes, and estuary waters, posing a threat to freshwater biodiversity and ecosystem resilience even more. In light of these challenges, it is highly unlikely that Ireland is going to meet its EU WFD legally binding objectives of 2027, with approximately 34% of Irish water bodies remaining at risk. There is a need to take urgent action. In-depth knowledge of the key drivers of Ireland's water quality is crucial to designing conservation strategies that function and in reinforcing EE programmes to facilitate active involvement of the public in sustainable management of water resources.

Given the plethora of water quality issues in Ireland, it is clear that effective monitoring and evaluation methods are required to track environmental changes and guide conservation efforts. Biomonitoring by macroinvertebrate sampling has evolved as a popular tool because to its reliability and accessibility. Macroinvertebrates are important bioindicators because they are non-migratory, have a narrow habitat range, and are easy to collect. Furthermore, their variable tolerances to pollutants, such as changes in dissolved oxygen, pH, and hazardous compounds, enable researchers to measure water quality with better precision and ecological significance (Tampo et al., 2021; McSorley, 2022).

The correlation between riverine fauna and organic pollution was systematically documented by European researchers A. H. Hassal in London (1850) and F. Cohn in Breslau in the mid-19th century, following a serious cholera outbreak (Moog et al., 2018; McSorley, 2022). Since then, particular attention has been paid to aquatic macroinvertebrates, whose presence, abundance and diversity serve as biological indicators of water quality due to their varying tolerance to pollutants and their close association with riverbed habitats. Today, a variety of biomonitoring tools and indices have been developed to classify and identify freshwater organisms, such as macroinvertebrates, in order to assess water quality.

Despite advances in biomonitoring tools, Citizen Science (CS), the involvement of the public in scientific inquiry, enabling non-experts to contribute to the collection and analysis of data (Silvertown, 2009; Bonney et al., 2014; Smets, 2023), remains a resource that has yet to be fully harnessed in Ireland. Strengthening CS programmes can be achieved through improved programme management, enhanced communication between initiatives, and more effective participant recruitment and retention (Donnelly et al., 2013; Krabbenhoft & Kashian, 2020; McSorley, 2022; Smets, 2023).

Freshwater Conservation and Citizen Science

In response to diminishing ambient water quality in Ireland, engagement in Citizen

Science (CS) water quality monitoring initiatives has been increasing (Weiner et al., 2022;Smets, 2023). Although participation has grown in recent years, CS still remains underutilised as a national strategy for freshwater monitoring, with considerable scope for expansion and integration into formal water management frameworks. CS offers numerous benefits, both to scientific research and to broader societal engagement.

One of its key advantages is its capacity to facilitate data collection on a large spatial and temporal scale, which may otherwise be unfeasible for individual researchers due to constraints of time and funding (Dickinson et al., 2012; Bonney et al., 2014; Turrini et al., 2018; Smets, 2023). One example of a citizen engagement tool in environmental monitoring is the Citizen Science Stream Index (CSSI). The CSSI was developed by Dr Simon Harrison of University College Cork and is funded by the Environmental Protection Agency (EPA) and the Local Authority Waters Programme (LAWPRO) (LAWPRO, n.d.). This index offers a quick and accessible method for evaluating river and stream conditions, making it particularly suitable for use in citizen science investigations.

The CSSI is based on six key macroinvertebrates that are used to assess water quality: three species that are sensitive to pollution, stoneflies (*Plecoptera*), flattened mayflies (*Heptageniidae*), and green caddisflies (*Rhyacophilidae*), and three that are tolerant of pollution and indicate poor water quality, leeches (*Hirudinea*), snails (*Gastropoda*), and waterlouse (*Asellidae*). The CSSI is a good example of how citizen engagement can contribute to effective environmental monitoring by simplifying macroinvertebrate-based water quality assessments. While such tools enhance public participation in scientific research, integrating digital technology into environmental education can further amplify their impact. This study explored the intersection of EE, CS, and educational technology to assess how digital tools, such as the AquaInverts App, can improve scientific literacy and freshwater conservation awareness among Irish primary school children. By examining the effectiveness of mobile applications compared to traditional learning methods, this research investigates how interactive, hands-on approaches influence student engagement, motivation, and knowledge retention.

Dissertation Structure

This dissertation is organised into six chapters, each building on the foundation established in the introduction. Chapter 1 outlines the study's background, research rationale, and the existing gap in EE, particularly regarding digital tools in freshwater conservation. Chapter 2 presents a literature review that critically examines the theoretical foundations and previous research

informing this study. Chapter 3 details the methodological approach, including the research design, data collection strategies, and analytical methods. Chapter 4 presents and interprets the findings, highlighting key insights into the effectiveness of the AquaInverts App in EE. Chapter 5 synthesises and discusses the results in relation to the wider literature. Finally, Chapter 6 presents the conclusions, discusses broader implications, offers recommendations, and identifies avenues for future research in digital EE and CS.

Chapter 2

Literature Review

Chapter Overview

This chapter provides an overview of previous studies that guide the current study. First, it traces the emergence of EE and the subsequent Education for Sustainable Development (ESD) agenda, highlighting the global milestones that have shaped contemporary school practice. Second, it clarifies the concepts and pedagogical frameworks that orient school-based Environmental Education, including experiential, place-based and inquiry-led approaches, as well as CS, and shows how each translates into classroom and fieldwork design. Third, it synthesises recent empirical work with primary-aged learners, with particular attention to learning outcomes, environmental self-efficacy, and the conditions that support pro-environmental action. Fourth, it reviews digital resources and CS platforms for water education, including tools for macroinvertebrate identification, and evaluates their affordances and limitations in primary settings. Finally, it identifies persistent gaps in assessment, equity and justice, and day-to-day classroom enactment that directly motivate the present study and shape its research questions. Taken together, these strands establish why digital tools and CS in primary Environmental Education for freshwater conservation are timely, locate the project within the wider field, and clarify how the literature informs the study design.

Development of Environmental Education

Addressing the socio-ecological crises of our time requires the active participation of all sectors of society, not just governments and NGOs, but individuals and communities as well. In 2023, NASA reported that the Northern Hemisphere experienced its hottest summer since records began in 1880, triggering wildfires in Canada, extreme heatwaves in the U.S., and devastating floods across Europe. These events serve as stark reminders of the very real and escalating consequences of climate change. Since the early 1970s, the United Nations has recognised Environmental Education (EE) as a vital response to these global challenges. A series of international conferences (United Nations, 1972; 1993; 2012; 2015) have consistently emphasised the transformative potential of education in promoting sustainability. Scholars echo this perspective, viewing EE as a catalyst for raising awareness and driving behavioural change (Kuthe et al., 2019; Souza et al., 2019; Williams & McEwen, 2021; Fauville et al., 2021; Hughes & Moscardo, 2023).

Although the term “Environmental Education” only emerged in the mid-20th century, its intellectual roots trace back to the work of 19th- and early 20th-century educators and thinkers. Sir Patrick Geddes, a Scottish botanist, is often cited as the first academic to formally link education with the environment, developing field-based teaching methods in the late 1800s (Palmer, 2002). His Outlook Tower in Edinburgh, established in 1892, remains a symbol of early environmental inquiry. Contributions from figures such as John Dewey, Jean-Jacques Rousseau, Friedrich Fröbel, and Maria Montessori further laid the groundwork for modern EE by advocating child-centred, experiential learning. These educators emphasised learning through direct engagement with nature, the senses, and one’s immediate surroundings, ideas that continue to shape contemporary outdoor and environmental education practices (Carter & Simmons, 2010).

In the early 20th century, naturalists like John Muir and Aldo Leopold shifted the environmental dialogue, for example, public and scholarly conversations about humanity's relationship with the natural world, towards conservation and ecological ethics. Simultaneously, the Nature Studies movement broadened these ideas into a more structured educational domain, paving the way for organisations such as the International Union for Conservation of Nature (IUCN), established in 1948 (Palmer, 2002). These foundational efforts culminated in a global milestone: the 1972 United Nations Conference on the Human Environment in Stockholm. Principle 19 of the Stockholm Declaration explicitly called for environmental education across generations, thereby solidifying its role in global sustainability efforts.

Over the past four decades, EE has developed into a diverse and interdisciplinary field, integrating ecological knowledge with educational theory, public policy, and community engagement. Despite widespread recognition and policy integration, the continued prevalence of climate-related disasters raises questions about the effectiveness and reach of EE initiatives. To provide a visual overview of key milestones in the development of EE, the timeline below maps out pivotal events and international frameworks that have shaped the field from 1948 to the present day. It highlights how EE has evolved alongside the global sustainability agenda, from conservationist beginnings to its current role in climate change education and digital engagement. This trajectory provides context for the rationale outlined in Chapter 1, where this dissertation examines the use of the App as a digital tool to support environmental learning and engagement.

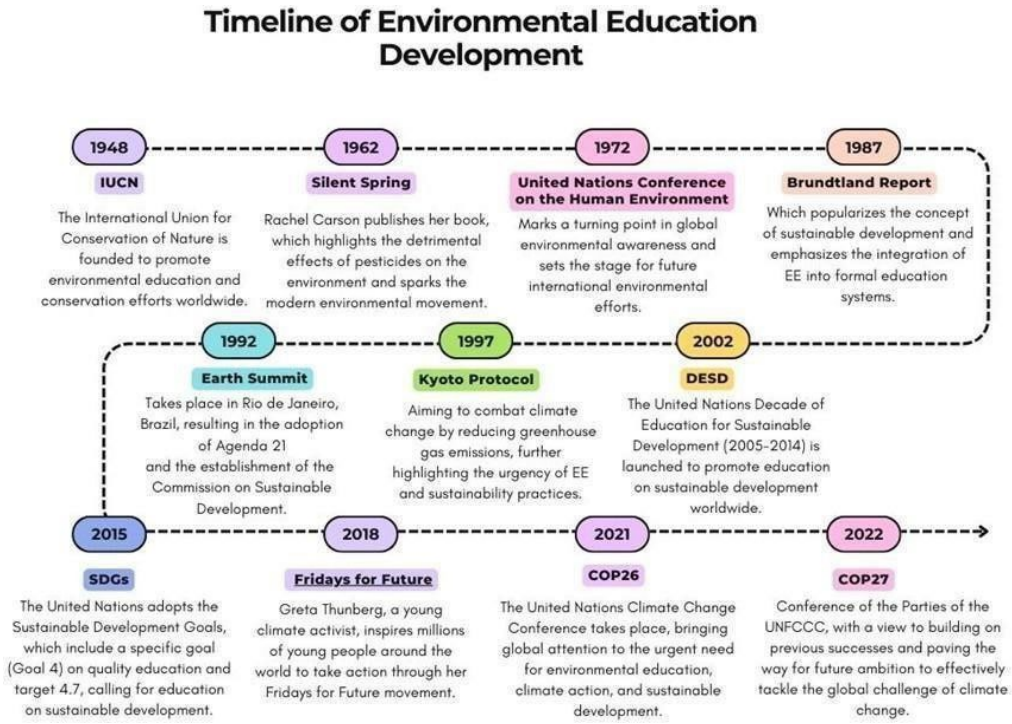


Figure 1: Timeline of Environmental Education Development. The graphic highlights the increasing global recognition of EE as a critical tool for sustainability, climate action, and social transformation.

Rather than offering a purely historical narrative, this literature review positions the field's evolution as a foundation for examining contemporary theories and pedagogical innovations in EE. From Geddes's field-based learning to UNESCO's global policy frameworks, EE has evolved from early conservationist efforts to a more holistic and transformative practice, focusing on sustainability, critical thinking, and civic engagement. This shift reflects broader educational trends that prioritise learner agency, cultural context, and socio-ecological justice. The next sections examine how recent research builds upon this legacy, particularly through approaches that engage children not only as learners but as active participants in shaping environmental futures. Key areas of focus include the use of digital tools to enhance ecological literacy and community-based learning models that ground education in lived, local experience.

Key Theoretical Frameworks

This section reviews EE research with a particular focus on studies involving children. It is organised thematically to address key trends and issues in the field. First, it identifies the main theoretical frameworks guiding contemporary EE research. Next, it highlights prominent research gaps, particularly relating to geographic representation and long-term impact. The section then examines methodological approaches commonly used by scholars, before concluding with an exploration of how technology is integrated into EE studies, including the use of mobile and digital tools.

The review analysed 34 peer-reviewed, open-access studies published between 2018 and 2023. These were primarily drawn from Environmental Education Research and The Journal of Environmental Education, which are leading journals in the field. The focus on open-access literature reflects a commitment to equitable knowledge sharing and ensures that the findings could inform educational practice across diverse contexts. This selection was guided by the relevance of the studies to child-centred EE, as well as their theoretical and methodological contributions. The goal was to map out recent directions in EE theory, particularly those informing innovative, participatory learning approaches.

This section offers an overview of the key theoretical frameworks identified across the selected studies. While not exhaustive of all EE theory, the analysis highlights the most frequently applied frameworks in recent literature involving children, environmental learning, and digital or community-based interventions.

Transformative Learning and Social-Ecological Resilience

Among the most prominent frameworks were *transformative learning and social-ecological resilience*, which appeared across multiple studies. Transformative learning theory, originally developed by Mezirow (1997), emphasises deep, reflective shifts in individuals' worldviews, empowering them to question assumptions and take informed action. In the context of EE, it supports critical engagement with environmental issues and personal responsibility. Social-ecological resilience, as used in EE research (Ruiz-Mallén et al., 2022), refers to the capacity of human and ecological systems to adapt, recover, and transform in response to environmental and social challenges. When combined, these frameworks provide a powerful lens for fostering both personal growth and community adaptability.

For example, Ruiz-Mallén et al. (2022) applied both frameworks to their study of community-led climate initiatives in Barcelona. Their findings showed that service-learning

models enhanced youth agency and self-efficacy, enabling adolescents to engage critically with climate action. Similarly, Souza et al. (2019), drawing on Freire and Maturana, emphasised dialogic, community-rooted learning as a foundation for sustainability. Both studies demonstrate how transformative approaches can build critical consciousness and collective environmental action, despite differing conceptual paths.

Environmental Literacy and Cognitive Development

Kuthe et al. (2019) and Cincera et al. (2022) applied the framework of environmental literacy and cognitive development to explore how knowledge and behaviour are shaped in youth. Kuthe's cluster analysis, conducted among teenagers in Germany and Austria, revealed disparities in climate awareness that underscored the need for tailored, context-sensitive interventions. Cincera's large-scale study of over 29,000 Czech students found that demographic variables such as gender and age influenced environmental attitudes. Importantly, the research showed that involving students in curricular decision-making enhanced their environmental agency.

These findings are especially relevant to the present study, which also aims to understand how young learners process and act upon environmental knowledge. While Kuthe and Cincera focused on formal educational settings, the current study extends this by integrating mobile technology into EE and situating learning in community and digital contexts. Both frameworks, like the current project, emphasise the importance of youth agency, but this study further explores how interactive tools may amplify that agency in more dynamic learning environments. In this way, the literature not only informed the research design but also helped position environmental literacy as both a cognitive and participatory process. Taken together, these strands serve as key building blocks that frame the present study, particularly in relation to youth agency, contextualised learning, and the use of digital tools to support participation in EE.

Post-Anthropocentric Frameworks

Weldemariam (2020) offered a post-anthropocentric lens, which challenges the dominant human-centred orientation in EE. Instead of prioritising human needs and experiences, this approach incorporates post-humanist and new materialist perspectives that recognise the agency and interconnectedness of all living and non-living entities. In this framework, nature is not merely a backdrop for human learning but an active participant in educational processes. While conceptually rich, its abstract nature poses challenges for practical implementation in primary education, particularly where curricula remain anthropocentric, treating nature mainly as a resource for human use rather than as a system in which humans are embedded. Nevertheless, this perspective opens the door for more inclusive, ecologically attuned thinking that reframes

children not just as learners about the environment, but as learners with and within it.

Place-Based and Relational Pedagogies

Häggström and Schmidt (2020) adopted critical place-based pedagogy, viewing natural environments as dynamic spaces for literacy and agency-building. In contrast, Cruz, Selby, and Durham (2018) used a relational approach rooted in community knowledge, especially within under-resourced areas. Both studies highlight the value of ecological learning grounded in students' local realities and cultural assets.

Storytelling and Imaginative Ecological Education (IEE)

Hughes and Moscardo (2023) and Häggström (2022) showed how storytelling and IEE can build emotional and cognitive ties to nature. Narrative structures, especially those drawing on science and indigenous worldviews, were found to be highly effective in promoting environmental stewardship and agency. IEE, in particular, empowered students to imagine alternative ecological futures through creative, classroom-based engagement.

Connectedness to Nature and Pro-Environmental Behaviour

Mullenbach et al. (2019) and Hoover (2021) examined the relationship between outdoor experiences and later environmental behaviour. Mullenbach emphasised structured residential environmental programmes that promote emotional bonds with nature. Hoover, meanwhile, categorised different outdoor activities and found that appreciative engagements (e.g., hiking) have a stronger long-term impact than consumptive ones (e.g., fishing). These studies collectively suggest that both structured and informal nature experiences can foster environmental responsibility.

Across these studies, most authors did not develop new theoretical frameworks but rather applied or adapted existing ones to specific educational contexts. For instance, Mullenbach (2019) and Hoover (2021) drew on well-established psychological theories of connectedness and behaviour, while Hughes and Häggström employed storytelling frameworks rooted in ecological literacy and Indigenous knowledge systems. Although not always explicitly theorised, these frameworks often shaped the design of activities, evaluation tools, and learning outcomes.

Among the frameworks reviewed, Transformative Learning, Environmental Literacy, and Place-Based Pedagogy appeared most frequently, suggesting their continued influence in contemporary EE research. However, emerging perspectives, such as Post-Anthropocentric and Imaginative Ecological Education (IEE), signal a shift towards more inclusive, affective, and ethically oriented approaches. This trend reflects a broader evolution in EE literature, from

primarily cognitive models to those that integrate emotion, identity, culture, and systems thinking.

Whole School Approach (WSA)

Orsdottir et al. (2023) explored the Whole School Approach (WSA) to Environmental Education (EE) in Irish primary schools, where EE is integrated across curriculum content, school leadership, and community engagement. The WSA is a systemic, institution-wide model that embeds sustainability not only in teaching and learning, but also in school policies, operations, and values. It encourages collaboration among teachers, students, families, and the broader community to foster a shared commitment to environmental responsibility. This model supports deep institutional transformation by positioning sustainability as a guiding principle for the entire school culture. However, the study also revealed persistent limitations, such as superficial student involvement, a lack of teacher training, and institutional barriers to interdisciplinary cooperation. These challenges highlight the gap between policy intention and practical implementation, suggesting that while WSA has strong conceptual promise, its real-world application requires more robust support structures and stakeholder buy-in.

This review of theoretical frameworks in EE reveals a rich and evolving field. Theories such as Transformative Learning, Social-Ecological Resilience, Environmental Literacy, Cognitive Development, and Post-Anthropocentrism provide educators with diverse tools to address cognitive, behavioural, and ethical dimensions of EE. Approaches like Place-Based Pedagogy, Storytelling, and the Whole School Approach reflect the growing emphasis on contextual, community-embedded practices. While some frameworks thrive in structured environments, such as Whole School Approaches or curriculum-integrated Cognitive Development models, others, like Imaginative Ecological Education or Place-Based Pedagogy, lean on the power of informal, experiential learning. This duality enhances the field's adaptability across various educational settings.

Ultimately, the value of any EE framework rests on how well conceptual strength meets practical delivery. Approaches that are holistic and adaptable, attentive to the entanglement of human and more-than-human agency, local participation, and learners' personal development, are most likely to advance environmental literacy and cultivate resilience across generations. Even so, fit matters. Transformative Learning and resilience-oriented models tend to thrive in community-led initiatives and service-learning, where reflection, agency, and collective problem-solving can take root.

By contrast, Environmental Literacy frameworks and cognitive-development

perspectives align more naturally with formal classroom structures and assessment routines. Post-anthropocentric and storytelling-based approaches often find their footing in early years and outdoor settings, where affect, imagination, and embodied experience can be foregrounded. Taken together, these contextual alignments point to a simple design principle: EE strategies should be selected and sequenced with the learner, the institution, and the surrounding sociocultural conditions in mind, rather than applied wholesale.

Research Gaps in EE

A clear research gap in recent EE literature is the persistent geographical bias. The majority of studies are concentrated in affluent regions such as Europe, North America, and Australia (Powell et al., 2023; Lin & Ardoin, 2023; Torsdottir et al., 2023). This imbalance limits the generalisability of findings to global contexts. Scholars like Koralage (2024) emphasise the need for EE frameworks to be adapted for diverse socio-economic and cultural realities, particularly in the Global South. Local priorities, educational infrastructure, and access to resources heavily influence EE implementation, yet remain underexplored.

Another significant gap concerns the lack of longitudinal studies. Researchers such as Kuthe et al. (2019) and Finnegan (2022) stress the need to evaluate how environmental attitudes and behaviours evolve over time, post-intervention. However, conducting long-term studies can be especially challenging in research involving primary-aged children, due to school transitions, consent requirements, and shorter attention spans. As a result, while longitudinal insight is valuable, studies involving younger learners may require modified, developmentally appropriate follow-up strategies to track impact over time without compromising feasibility.

The promising role of storytelling in EE is well-documented (Hughes & Moscardo, 2023). Narrative-based approaches have been shown to foster emotional and cognitive connections to nature; however, further research is needed to understand how these methods can be effectively tailored to different cultural contexts and age groups. Despite its potential, the long-term impact of storytelling on sustained pro-environmental behaviour remains underexplored. Building on these insights, this review highlights the need for future research to examine how various narrative forms, oral, digital, and visual, can be intentionally designed and delivered to maximise learner engagement. In particular, studies should consider how storytelling can be adapted for use with younger audiences, and how its effects might be evaluated over time to assess durability and behavioural impact.

Methodologies in EE Research

Given that this dissertation's methodological choices are detailed in Chapter 3, this subsection briefly summarises dominant methodological patterns in recent EE research to contextualise the approach adopted in this study. An analysis of 34 reviewed studies reveals a clear
dominance of qualitative methodologies, particularly those employing participatory approaches, case studies, and thematic analysis. For instance, Ruiz-Mallén et al. (2022) used interviews and document analysis to investigate community-led resilience programmes. Participatory Action Research (PAR) featured prominently, especially in studies by Fauville et al. (2021) and Williams & McEwen (2021), which explored virtual reality tools and children's flood resilience learning, respectively.

Interviews and focus groups remain widely used: Gericke and Torbjörnsson (2022) employed semi-structured interviews to evaluate ESD implementation, while Ruck and Mannion (2021) used focus groups to explore students' conservation experiences. Meanwhile, mixed methods are gaining traction. For example, Torsdottir et al. (2023) integrated surveys with focus groups to assess student engagement in school sustainability initiatives. To illustrate the range of methodological approaches, a summary of selected studies is provided in the table below.

Table 1: Sample of Methodologies Used in Recent EE Studies

Study	**Methodology**	**Focus Area**
Ruiz-Mallén et al. (2022)	Qualitative – Interviews, Docs	Community-led resilience, Barcelona Youth
Fauville et al. (2021)	Participatory Action Research (PAR)	VR + ocean acidification education
Williams & McEwen (2021)	PAR	Children's flood resilience + VR
Gericke & Torbjörnsson (2022)	Semi-structured Interviews	ESD implementation in schools
Ruck & Mannion (2021)	Focus Groups	Student conservation experiences
Torsdottir et al. (2023	Mixed Methods (Surveys + Focus Groups)	Whole School Approach in Irish Schools

Document analysis, as used by Grauer et al. (2022), and thematic coding, as applied by Häggström & Schmidt (2020) and Couceiro et al. (2023), offer further insights into curriculum

design and pedagogical strategies. These methods uncover patterns in data that help explain EE outcomes. In conclusion, methodological diversity is a strength in EE research. There is no singular best method; rather, researchers must align their approaches with the context, learners, and research goals. Future work could benefit from integrating advanced technologies such as digital storytelling and virtual reality, which broaden the methodological toolkit and deepen the field's relevance in a digitally connected world.

Notably, a small number of studies reflect a similar methodological orientation to that adopted in this research. For example, Fauville et al. (2021) and Williams & McEwen (2021) both employed participatory and technology-enhanced approaches to engage children in environmental learning using digital media and virtual reality. These studies underscore the potential of immersive and interactive tools to enhance engagement, especially among younger learners. However, such approaches remain underrepresented in the broader EE literature, reinforcing the value of this study's contribution.

Environmental Education and Technology

This section explores the potential for digital technologies to enhance EE, particularly in light of this dissertation's focus on a mobile app-based educational intervention. While a growing body of work addresses technology in education more broadly, relatively few studies explicitly connect digital tools with EE for children. Among the 34 reviewed papers, only three directly addressed this intersection, revealing a notable research gap within the specific scope of this review (i.e., child-focused, open-access studies between 2018 and 2023). For example, Fauville et al. (2021) investigated the use of virtual reality to teach ocean acidification. Their participatory action research approach demonstrated virtual reality's potential to enhance visualization, foster empathy, and empower learners through immersive environmental storytelling.

Similarly, Lin and Ardoin (2023) used remote digital diaries to examine how families engage with environmental topics at home via digital media. While technology supported meaningful dialogue, the study also noted the digital divide, unequal access to devices, connectivity, and digital skills, as a barrier to equitable access. Smith et al. (2023) evaluated the use of digital tools in a Girl Scouts science engagement programme, finding some success but also limitations related to sample size and narrow technological applications. Although promising, these studies suggest that the use of technology in EE, particularly for younger learners, remains underexplored and potentially underutilised. This reinforces the value of further inquiry into how tools such as mobile apps, virtual reality, and digital storytelling can be integrated into child-centred EE in inclusive and scalable ways.

Despite these promising developments, there remains a limited understanding of the long-term effects of technology EE on sustained behavioural change. The current body of literature reviewed appears to lack comprehensive evaluations of how tools such as virtual reality, mobile apps, or digital storytelling influence enduring environmental action, particularly when used with younger learners. Additionally, many of the studies analysed either did not include or did not report on underprivileged and rural groups, pointing to a need for more inclusive and scalable technological interventions within EE.

In summary, while emerging research highlights the potential of technology to enrich environmental learning, its integration into EE frameworks, especially in formal education settings, remains relatively underdeveloped. There is scope for further research to explore how digital innovations can be effectively and equitably deployed to support environmental engagement, especially across diverse socio-economic and cultural contexts.

Summary of the EE Research Review

The body of EE research from 2018 to 2023 demonstrates diverse theoretical approaches and methodologies. However, persistent gaps continue to limit its broader impact. Chief among them is a geographic imbalance, with most studies conducted in affluent Western nations. This trend perpetuates an Eurocentric lens and constrains the applicability of EE frameworks in Global South contexts, where socio-economic and environmental challenges often differ markedly. While this review has sought to represent a broad and relevant sample of recent EE research, it is important to acknowledge that some studies, particularly those outside the open-access or English-language domain, may not have been captured. As such, the geographic gap described here reflects patterns within the reviewed literature, but not necessarily the full global landscape of EE scholarship.

Additionally, there is limited integration of critical socio-environmental concepts such as environmental justice, environmental racism, and greenwashing within mainstream EE research. The work of Bullard (2005) highlights the unequal environmental burdens faced by marginalised communities, insights that remain largely absent in traditional EE discourse. Addressing these dimensions would enable EE to move beyond general sustainability narratives and instead promote a more inclusive, justice-oriented educational framework. Environmental justice, for instance, draws attention to the disproportionate exposure to ecological harm experienced by low-income and racialised communities. It advocates for the fair treatment and meaningful involvement of all people in environmental decision-making,

regardless of race, income, or geography (Schlosberg, 2007).

Environmental racism further exposes systemic inequalities, such as the siting of hazardous waste facilities and polluting industries near minority populations, often without adequate community consultation (Bullard, 1993; Taylor, 2014). These injustices highlight the need for an EE that not only fosters ecological literacy but also equips learners to analyse power, privilege, and systemic oppression. In parallel, greenwashing, the corporate practice of overstating or misrepresenting environmental credentials, poses another critical challenge. Scholars such as Lyon and Montgomery (2015) argue that greenwashing undermines genuine sustainability efforts and manipulates public perception. As such, EE must empower learners to critically evaluate corporate messaging, question environmental claims, and develop ethical discernment, aligning educational practice with broader goals of equity and environmental accountability.

In conclusion, EE research is evolving but remains constrained by geographical and conceptual limitations. There is a need for future studies to centre diverse voices and integrate critical perspectives to address the complex demands of the environmental crises of our time. In this way, a truly transformative EE can provide a means of confronting global inequalities and empower learners to act not only as environmental stewards, but as informed, ethical agents of change.

Environmental Education in Irish Primary Schools

Given that the empirical component of this research takes place in Irish primary schools, it is essential to contextualise how EE has been historically integrated into the Irish curriculum. O'Malley and Pierce (2023) offer a comprehensive historical analysis of EE in Irish primary education, tracing its development from 1872 to 2021. They noted that although EE has maintained a presence in curricula, it has typically played a peripheral role, often left to individual teacher discretion. Their review reveals how key events, such as Irish independence and EU membership, shaped educational priorities, but also highlights persistent challenges, including curricular overload, limited time, and a lack of national standards for EE delivery.

Expanding this critique, Pierce (2023) provides an ethnographic account of outdoor education through the lens of McDonaldization (Ritzer, 1983). Conducted over ten months across four Outdoor Education and Training Centres, the study describes how principles of

efficiency, predictability, and standardisation have shaped Irish outdoor education practices. While these centres aim to provide experiential learning, the study suggests that participants are often reduced to data points, with learning experiences becoming formulaic and depersonalised. The lack of a clear national definition of outdoor education contributes to its marginalisation, and although Pierce effectively diagnoses these systemic issues, the study would benefit from more explicit recommendations for reform.

In contrast, a report by the National Council for Curriculum and Assessment (NCCA) (Pike et al., 2023) presents a more optimistic perspective. It reviews the evolving role of Social and Environmental Education (SEE), which includes geography, history, and education about religions and beliefs, within the Primary Curriculum Framework. Pike et al. (2023) argue that SEE can meaningfully engage children's lived experiences, cultivating environmental stewardship, empathy, and democratic citizenship. They emphasise the importance of teacher expertise and student agency, though a more critical appraisal of practical implementation challenges is warranted.

Together, these studies reveal the uneven and sometimes contradictory integration of EE in Irish primary schools. Despite increasing curricular recognition, EE often remains marginal, subject to institutional pressures and a lack of cohesive strategy. The dominance of efficiency-focused models, as illustrated by Pierce, risks diluting the transformative potential of outdoor learning. Meanwhile, national curriculum reform efforts acknowledge the value of EE, yet still lack robust mechanisms to ensure consistent, impactful delivery across schools.

These studies highlight structural constraints, such as curriculum overload and inconsistent delivery, and suggest the importance of evidence-based strategies to support high-quality EE. There is a clear need for national guidelines, investment in teacher training, and curriculum models that embed EE as a central, not peripheral, aspect of education. By doing so, Ireland can better prepare young learners to engage critically and responsibly with the environmental challenges of their time.

Citizen Science and Children's Participation

Citizen Science (CS) refers to scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists (Oxford, 2014). The European Commission (2016) aligns with this definition, further associating CS with public engagement, outreach, and science education. The European Citizen Science

Association (ECSA) expanded on this with ten principles emphasising meaningful citizen participation, mutual benefits, scientific outcomes, data accessibility, and ethical standards (ECSA, 2015).

The term "Citizen Science" was independently coined by Rick Bonney (1996) and Alan Irwin (1995). Bonney defined CS pragmatically, as volunteer-based data collection (e.g., birdwatching), focusing on public understanding and scientific data enhancement. In contrast, Irwin's philosophical perspective advocated a democratised science, receptive to public concerns and inclusive of local, contextual knowledge. This dual understanding of CS, as both "science for the people" and "science by the people", remains influential today.

CS has expanded considerably, now spanning areas from biodiversity monitoring to air pollution mapping. It fosters cross-disciplinary innovation, yet meaningful engagement with policymakers and practitioners remains limited (Hecker et al., 2018; Makuch & Aczel, 2018). Platforms like Zooniverse exemplify the scalability of CS, hosting projects across eleven disciplines and engaging over a million contributors worldwide.

Children and Citizen Science

The adaptability of CS creates opportunities for involving children in scientific research. Studies highlight how children's curiosity and eagerness to explore can drive meaningful engagement (Jenkins, 2011; Makuch & Aczel, 2018). According to ECSA's principles, CS projects should promote learning, making child participation not only feasible but beneficial for skill development and environmental awareness. Kelemen-Finan et al. (2018) evaluated a biodiversity-focused CS initiative involving over 400 students (aged 8–18) in Central Europe. The school-based project assessed Intended Learning Outcomes (ILOs) such as motivation, interest, and attitudes. Younger students (aged 8–10) reported greater engagement and contributed more data. While outcomes were positive, the study highlighted gaps in evaluation frameworks and called for more rigorous instruments.

Miczajka et al. (2015) tested data reliability by comparing ecological observations made by children and scientists. While children were accurate in seed counting, discrepancies emerged in vegetation cover and height estimations. The study emphasised the need for simplified task design and specific training, raising broader concerns about the quality of child-collected data. Varaden et al. (2021) engaged primary school children in air quality monitoring using sensor-equipped backpacks. The study yielded valuable exposure data and raised awareness of pollution risks. However, concerns around sensor accuracy and socioeconomic

bias limited the generalisability of findings. The initiative nonetheless demonstrated the potential of school-based CS projects in fostering environmental consciousness.

Similarly, Castagneyrol et al. (2019) compared schoolchildren, untrained adults, and scientists in ecological data collection. Although schoolchildren overestimated predation and herbivory rates, calibrated data remained useful. The findings reinforced that careful protocol design and quality control are essential for incorporating children in large-scale ecological monitoring. Other studies further support the educational value of CS for children. Kountoupes

and Oberhauser (2008) explored monarch butterfly monitoring, highlighting children's enthusiasm and ability to contribute with adult guidance. Teed (2023) evaluated a water quality project, similar in scope to this dissertation, and found increased awareness and intent to act, although self-efficacy did not measurably increase.

These projects collectively show that children can be effective contributors to CS when provided with structured guidance and appropriate tools. School-based projects foster engagement, align with curricular goals, and promote teacher-led facilitation. Yet, challenges persist in ensuring data quality and long-term educational impact. Many studies lack follow-up on whether participation translates into sustained scientific literacy or behaviour change. In conclusion, while child participation in CS offers numerous short-term benefits, such as engagement and skill development, future projects must address methodological rigour, validation procedures, and longitudinal outcomes. Integrating children into CS, particularly in environmental projects, holds substantial promise, but it must be carefully designed to ensure both educational value and scientific reliability.

Educational Apps: Enhancing Learning Through Mobile Technology

The proliferation of mobile devices such as smartphones, tablets, and iPads has significantly reshaped educational landscapes, prompting extensive research into educational apps. This section synthesises key findings from the past decade to identify best practices and current gaps in app-based learning across early childhood, primary, and secondary education (Smith et al., 2018; Bano et al., 2018; Papadakis et al., 2017; Zydney & Warner, 2016; Gómez Domingo & Badia Garganté, 2016; Hirsh-Pasek et al., 2015; Kucirkova et al., 2014).

Educational apps studied include tools for digital storytelling, gamification, scientific exploration, and learning management. For instance, Kucirkova et al. (2014) evaluated *Our*

Story, a story-making app that fostered creativity and collaborative engagement in young learners. Zydney and Warner (2016) identified features like scaffolding and location-aware content as key elements in science-focused mobile apps. Similarly, Papadakis et al. (2017) found that while many preschool apps lack educational substance, those promoting open-ended play supported creativity and skill development.

A summary of research outcomes is presented below:

Table 2: Studies about Educational Apps

Study & Authors	**App Type & Focus**	**Key Findings**	**Research Gaps**
Kucirkova et al. (2014)	Story-making app (Our Story)	Higher individual and collaborative engagement, creativity, and collaboration	Inconsistent engagement data; limited scope
Zydney & Warner (2016)	Mobile science learning apps	Effective features include scaffolding, location-awareness, multimedia, and collaboration	Need for research on higher-level cognitive outcomes
Papadakis et al. (2017)	Greek educational Android apps for pre-schoolers	Many apps lack educational value; successful apps support open-ended activities, creativity	Need for long-term studies and research across diverse populations
Pechenkina et al. (2017)	Gamified mobile learning app for higher education	Increased student retention and academic performance; enhanced engagement through gamification	Need for longitudinal studies and research across disciplines
Smith et al. (2018)	Digital educational tools for early childhood	Improved mathematical skills, engagement, problem-solving; valuable classroom resource	Long-term impact; diverse populations; teacher training
Hirsh-Pasek et al. (2015)	General educational apps	Many apps lack elements of effective learning; need for active, engaged, meaningful experiences	Need for empirical evidence and alignment with learning principles
Gómez Domingo & Badia Garganté (2016)	Educational technology in primary education	Positive teacher perceptions on mobile tech; varied app usage; impact on engagement and learning	Need for longitudinal studies and diverse educational contexts
Bano et al. (2018)	Mobile learning in secondary science and math	Effective for inquiry-based, collaborative, realistic learning; need for diverse, mixed-methods research	Need for replication, longitudinal studies, diverse topics

Key Insights

Successful educational apps have the potential to foster active, meaningful, and socially interactive learning. Open-ended features that stimulate creativity and collaboration are especially effective (Kucirkova et al., 2014; Papadakis et al., 2017). Gamification elements, such as digital badges and leader boards, enhance motivation but require further study to assess long-term efficacy (Pechenkina et al., 2017). Hirsh-Pasek et al. (2015) emphasised that many apps fail to align with established educational theories. Apps grounded in the science of learning are more likely to produce positive outcomes (Hirsh-Pasek et al., 2015). Developmentally appropriate content, interactive features, and collaborative tasks are essential for enhancing cognitive engagement.

Despite their promise, many educational apps fall short due to limited interactivity, inadequate alignment with pedagogical frameworks, and lack of empirical validation. Research gaps persist, including the need for longitudinal studies, diverse participant samples, and improved teacher integration.

Future app development should prioritise:

- Interactive and developmentally appropriate features;
- Opportunities for collaborative learning and peer interaction;
- Alignment with pedagogical principles;
- Regular updates and robust evaluation;
- Accessibility for diverse learners, including those with special educational needs.

These priorities reflect the patterns highlighted across the reviewed studies (Hirsh-Pasek et al., 2015; Zydney & Warner, 2016; Kucirkova et al., 2014; Papadakis et al., 2017; Smith et al., 2018). In summary, educational apps have the potential to transform learning, but their true value depends on thoughtful design, rigorous testing, and sustained integration into pedagogical practice.

Chapter Summary

This chapter has reviewed the evolving landscape of EE, CS, and educational technologies, with a focus on their integration in formal education and child-centred approaches. The literature reveals a field that is expanding in scope and ambition, yet still constrained by notable gaps, including a disproportionate focus on high-income regions, a lack of longitudinal studies, and limited engagement with frameworks such as environmental justice

and greenwashing. In the context of Irish primary education, EE remains largely peripheral,
shaped by systemic limitations and teacher discretion, despite its recognised potential for fostering critical thinking, empathy, and active citizenship.

The exploration of CS initiatives, particularly those involving children, has highlighted the potential of participatory science to deepen engagement and learning, although questions about data reliability and long-term educational outcomes persist. Similarly, the analysis of educational apps illustrates how technology can enhance learning when grounded in strong pedagogical design, yet much work remains to ensure inclusivity, empirical rigour, and sustainability. These findings have directly informed the design of this study, reinforcing the importance of context, inclusivity, and learner engagement in EE research. In the next chapter, the methodological framework guiding this investigation will be outlined. Chapter 3 will detail the research design, data collection methods, and analytical approaches used to examine the impact of a technology-enhanced EE intervention with children in Irish primary schools.

Chapter 3

Research Methodology

EE research is characterised by a diversity of methodological approaches that reflect its interdisciplinary and applied nature. These approaches range from traditional quantitative methods grounded in positivist paradigms to qualitative and participatory methodologies that explore lived experiences, contextual knowledge, and community-based inquiry (Ardoin et al., 2020; Stevenson et al., 2013). This methodological diversity attests to the core of environmental issues, which often require both empirical measurement and interpretative understanding. EE researchers have thus called upon a progressively broad scope of theoretical and epistemological traditions, such as constructivism, critical theory, and socio-ecological perspectives, to address complex environmental and educational questions (Rousell & Cutter-Mackenzie-Knowles, 2020).

Similarly, the concept of CS adds various viewpoints to research approaches, notably in the disciplines of environmental and ecological sciences (Bonney et al., 2016). The methodological landscape in EE research has traditionally been dominated by quantitative and positivist approaches (O'Malley, 2014). However, there is a growing recognition of the value of qualitative and mixed-method approaches in capturing the nuanced experiences and perspectives of both educators and learners in environmental education contexts (Stevenson et al., 2013).

In light of these evolving methodological trends, this study adopts a pragmatic research design to evaluate the integration of digital technology into EE practice. The relative complexity of both the EE and CS contexts required a reasonably flexible yet considered design, which allowed for intervention comparison within real school education contexts, while also acknowledging the limitations of working with schools. As participants weren't randomly assigned, school staff designated school classes to be control or experimental groups, enabling a valid comparative framework to be examined in authentic learning environments.

This chapter outlines the research design and methodology adopted in the study, including its rationale, data collection instruments, and procedures. It begins with an overview of the instruments and study setting and concludes with a description of the data analysis strategy employed.

The instruments for this study

This research project investigates children's learning and engagement in an EE and Science Outreach workshop on freshwater conservation. The study compares two delivery approaches for the same workshop activities: (1) using the App and (2) using a traditional paper-based identification method. In line with the study's research questions, the focus is on how children perceive and interact with each approach in a workshop setting, and how they perceive their ability to contribute reliable scientific information as citizen scientists.The AquaInverts App was one of the study instruments used to support macroinvertebrate identification in the workshop. Developed by a research team at Dundalk Institute of Technology, in collaboration with the Atlantic Salmon Trust, ORCCA, Martin McGarrigle, Ken Whelan, and the National Federation of Group Water Schemes (NFGWS), and supported by LAWPRO and Louth Leader, the app was designed to facilitate freshwater macroinvertebrate identification in both citizen science and educational contexts. The app includes key features such as a macroinvertebrate identification guide, a scoring system based on the CSSI, and a school-friendly mode designed for younger users. This version offers simplified navigation and child-appropriate language, making it suitable for use with pupils aged 8–12.



Figure 2: AquaInverts Home Screen

Although the workshops were conducted indoors, the AquaInverts app was utilised to simulate a realistic fieldwork experience. In preparation for each session, the researcher performed kick sampling (a biomonitoring technique used to assess river water quality by collecting aquatic invertebrates from the streambe), in local streams to collect macroinvertebrate specimens. These live samples were brought into the classroom to enable students to observe and identify freshwater invertebrates first-hand. This approach preserved

the authenticity of the sampling process while maintaining a controlled and logistically feasible environment for younger participants. As shown in Figure 2, the app's school mode opens with a simple login interface, allowing students to enter their school's name, class, and age. This ensures that each session is contextualised and supports consistent data entry across different groups.

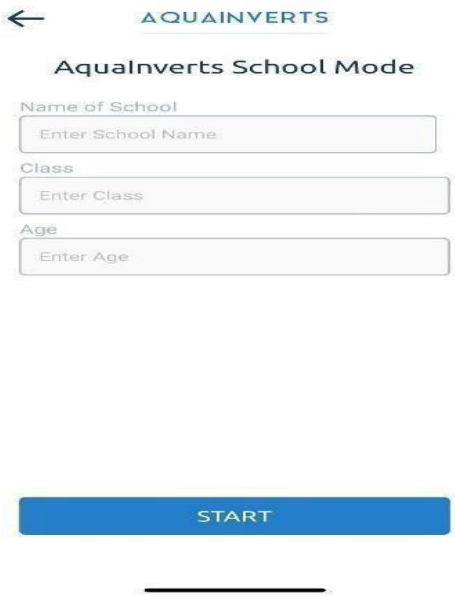


Figure 3: AquaInverts School Mode login screen

Although students did not conduct the kick test themselves, the Kick Test timer feature (Figure 3) was introduced and explained by the researcher as part of the workshop. The app displays a three-minute countdown alongside an instructional video featuring freshwater ecologist Martin McGarrigle, who demonstrates how to clean and prepare a macroinvertebrate sampling tray. This visual aid was used to familiarise students with the scientific procedure and build understanding of field ecology methods.



Figure 4: Kick Test interface in school mode

Following the researcher's introductory presentation, which provided background on freshwater macroinvertebrates and demonstrated the identification process, the live samples, previously collected from local streams, were distributed to the students. Each group of four to five students received a white tray containing a unique set of specimens. This setup enabled students to work directly with authentic biological material, creating an immersive and hands-on learning experience within the indoor classroom setting. Using the AquaInverts app in school mode, each group then worked collaboratively to identify the organisms in their tray. The app guided them through a structured series of visual prompts and binary questions (e.g., "Does it have a shell or a case?" / "Does it have legs or a tail?"), helping students narrow down the identity of each specimen based on observable characteristics.



Figure 5: Identification Interface – Shell or Case Recognition

An example of the app's early-stage identification prompt, encouraging students to assess whether the organism has a visible shell or constructed case.



Figure 6: Identification Interface – Legs or Tail Check

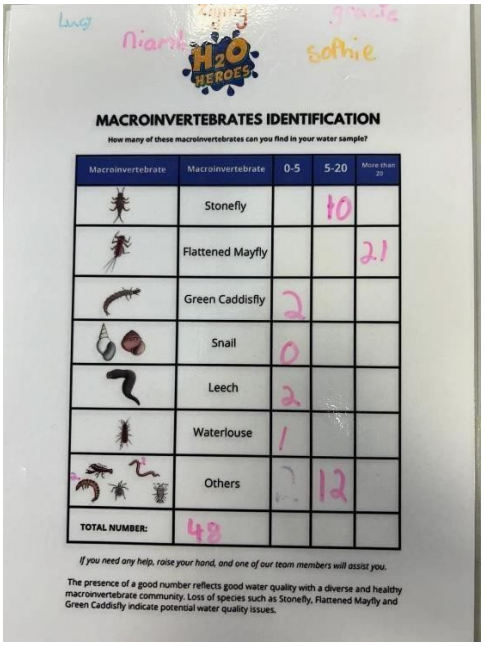
Upon confirming a match, the app displayed the identified species and invited students to record the number of individuals macroinvertebrates observed in their sample.

Figure 7: Confirmation and Data Logging Screen



Once a species, such as a Stonefly Nymph is identified, students are prompted to input the quantity observed. This interactive and scaffolded process supported both individual observation skills and group decision-making. While field conditions were not totally possible indoors, the combination of macroinvertebrate, the app, and peer collaboration allowed students to engage meaningfully with the experience in a format appropriate for their age and learning environment.

Both the control and experimental groups participated in the same workshop, which included an introductory presentation by the researcher, handling of live freshwater macroinvertebrate samples, and guided discussions on biodiversity and water quality. The only variable that differed between the two groups was the instrument used for macroinvertebrate identification. The control group used a traditional paper-based method to identify and record macroinvertebrates. Working in groups of four to five, each group received a printed Macroinvertebrates Identification Chart (see Figure 7) along with a white tray containing live specimens collected by the researcher. The chart included colour illustrations of key aquatic species and three columns for recording organism abundance (0–5, 5–20, and more than 20 individuals).



MACROINVERTEBRATES IDENTIFICATION

How many of these macroinvertebrates can you find in your water sample?

Macroinvertebrate	Macroinvertebrate	0-5	5-20	More than 20
	Stonefly		10	
	Flattened Mayfly			21
	Green Caddisfly	2		
	Snail	0		
	Leech	2		
	Waterlouse	1		
	Others		12	
TOTAL NUMBER:	48			

If you need any help, raise your hand, and one of our team members will assist you.

The presence of a good number reflects good water quality with a diverse and healthy macroinvertebrate community. Loss of species such as Stonefly, Flattened Mayfly and Green Caddisfly indicate potential water quality issues.

Figure 8**:** Control Group Macroinvertebrate Identification Chart

This method facilitated species identification through direct visual comparison and provided an opportunity for students to manually put the data. A final score of all macroinvertebrates found was entered at the bottom of the chart, encouraging reflection on species diversity and what it might indicate about water quality. By holding the structure, content, and learning objectives of the workshop constant, and altering only the identification instrument, the study ensures a valid comparison between digital and non-digital approaches. This design enabled a focused investigation into how the use of mobile technology influenced engagement, learning outcomes, and perceptions of scientific capability among primary school students.

The setting for the study

The fieldwork was conducted in three primary schools across County Louth and County Monaghan, Ireland. The pilot study took place in March 2024 in Drogheda, County Louth, while the second phase occurred in May and June 2024 in Blackrock, County Louth, and Latnamard, County Monaghan. These schools were selected based on their existing engagement with Dundalk Institute of Technology, including prior participation in science outreach events and Science Week activities. While the study initially aimed to involve two 4th-class groups per school, Latnamard National School, being a small rural school, operates mixed-age classrooms. Therefore, participants from Latnamard included a mixed 3rd and 4th class group, and a mixed 5th and 6th class group, aged 9-12 years old. This reflects the authentic educational structure of the school and adds to the ecological validity and contextual richness of the study.

Furthermore, the chosen schools represent a diverse socio-economic and geographical profile, including both urban (e.g., Drogheda and Blackrock) and rural (e.g., Latnamard) communities. This diversity allowed the study to assess the impact of the environmental education intervention across different demographic and educational contexts, contributing to a more comprehensive understanding of its applicability and relevance. The pre-existing relationships with the schools also facilitated smoother access, ethical clearance, and collaborative planning of the workshop.



Figure 9: Workshop at Drogheda, Blackrock and Latnamard.

The study involved dividing pupils into two groups: an experimental group utilising the AquaInverts App for macroinvertebrate identification, and a control group employing a traditional paper-based method of recording results. Both groups participated in a three-hour workshop designed to introduce children to fundamental environmental science concepts, including the importance of water, its properties, and the role of macroinvertebrates as bioindicators of water quality. The workshop served to establish a conceptual foundation relevant to the ecological themes of the research. This information was shared with all participating teachers two weeks prior to the workshop. Full workshop details can be found in Appendix A.

As outlined earlier, in order to create a more authentic scientific experience, live macroinvertebrates were collected by the researcher from nearby streams and transported to the schools for observation and identification (see Figure 9). The students were explicitly instructed to treat the organisms with care and respect. After the session, all specimens were safely returned to the streams from which they had been collected. This experiential learning approach allowed pupils to engage directly with real biological material, reinforcing key ecological concepts through active participation.



Figure 10: Researcher collecting macroinvertebrates for the workshops

Methodology

This study employed a quasi-experimental design to evaluate the impact of the educational intervention. This approach was appropriate for the research aims, as it enabled the comparison of post-intervention outcomes between an experimental group and a control group. Quasi-experimental designs offer a robust methodological framework for evaluating educational interventions in real-world EE settings, particularly where randomisation is impractical (Shadish et al., 2002). In EE research, they are especially valuable for assessing the effectiveness of programmes aimed at promoting pro-environmental behaviours and attitudes.

Recent studies have demonstrated the effectiveness of quasi-experimental designs in capturing measurable impacts of EE interventions. For example, Ardoin et al. (2020) conducted a systematic review of EE programmes and found that while many studies reported positive outcomes, only a subset applied quasi-experimental methods to evaluate behaviour change and ecological outcomes with rigour. Similarly, Şimşek (2024) used a quasi-experimental design to examine the impact of augmented reality-supported activities in early childhood EE. Simsek (2014) findings revealed significantly improved environmental comprehension among children exposed to interactive digital content compared to a traditional control group.

Further evidence of the utility of quasi-experimental methods can be found in studies exploring the health and social benefits of environmental interventions. Ward Thompson et al. (2019) assessed the outcomes of the "Woods In and Around Towns" (WIAT) programme in deprived Scottish communities. Their quasi-experimental evaluation found significant increases in participants' physical activity, connectedness to nature, and social cohesion.

These effects were particularly pronounced among individuals who engaged with nearby green spaces, demonstrating the role of proximity and active participation in nature- based interventions. Quasi-experimental approaches are also valuable in CS and school-based contexts. Ballard et al. (2021) evaluated the outcomes of youth-focused CS initiatives and found that structured participation led to increased environmental science agency and civic engagement.

These findings support the integration of quasi-experimental designs in formal educational environments, where ethical and logistical constraints may prevent randomisation, but causal inference is still crucial for evaluating impact. Quasi-experimental methods allow for the systematic evaluation of educational initiatives without compromising ecological validity, accommodating the complex nature of educational environments. This approach supports evidence-based decision-making in EE by providing reliable estimates of programme outcomes, even in the absence of random assignment. As such, quasi-experimental research represents a rigorous and adaptable alternative to mixed methods when evaluating the practical implementation and impact of EE and CS interventions.

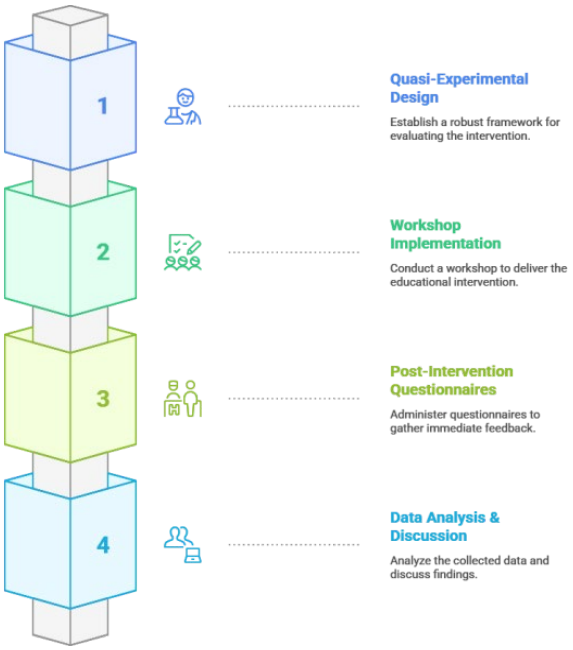


Figure 11: illustrates quasi-experimental implementation, including key stages such as data collection, design adaptation, and impact analysis

In conclusion, the quasi-experimental design provided a pragmatic and rigorous approach for evaluating the educational intervention. By enabling the comparison of outcomes between intervention and control groups, this method allowed for meaningful insights into the effectiveness of the programme. Quasi-experimental methods offer a robust and practical alternative for evaluators in EE and CS research, particularly in complex

real-world contexts where randomisation is not feasible. Building on this methodological foundation, the study now turns to the core research questions that guided the research design and data collection. These questions reflect the study's focus on evaluating the pedagogical and technological components of the EE intervention, particularly in relation to children's learning experiences and their perceived roles as contributors to the citizen science initiative.

Research Questions

This study aims to address the following main research question: How do EE activities enhance children's awareness of water conservation and the environment, and what role does digital technology play in this process?

To explore this overarching question, the following sub-questions are investigated:

3. How do children perceive and interact with a mobile app designed for environmental education in a workshop setting, and how does their engagement compare to those using a traditional paper-based method?

4. How do children perceive their ability to contribute reliable scientific information as citizen scientists, and does this perception differ between those using the AquaInverts mobile app and those using traditional paper-based methods?

Research Objectives

This study aims to evaluate an EE and Science Outreach workshop on freshwater conservation by comparing two delivery approaches, an app-based approach (AquaInverts) and a traditional paper-based approach, among primary school children in Ireland. Specifically, it seeks to:

1) Examine how children perceive and engage with the workshop activities when using the AquaInverts App compared to a traditional paper-based identification method.
2) Investigate how children perceive their ability to contribute reliable scientific information as citizen scientists, and whether this perception differs between the app-based and paper-based approaches.

This study uses a quasi-experimental design to enable comparison between the two approaches within real school settings. As participants were not randomly assigned, classes were designated as control (paper-based) or experimental (app-based) groups by school staff. This design was appropriate for addressing the research questions, as it allowed the workshop to be delivered under authentic classroom conditions while still supporting a structured

comparison of pupils' experiences across the two approaches.

Measurement Instruments and Scale Adaptation

Given the multifaceted nature of this research, the study employed adapted measurement instruments to assess both student engagement with digital tools and their perceived scientific self-efficacy as citizen scientists. These instruments were selected and modified to ensure age-appropriateness, contextual relevance, and methodological rigour. The control group questionnaire was adapted to suit the paper-based condition by rewording app-specific items to refer to the printed identification materials and workshop activity, while retaining the same underlying constructs (e.g., perceived usefulness/learning, clarity, and enjoyment) and the same five-point Likert response format.

Assessing Engagement with Educational Technology

Over recent decades, researchers have employed various theoretical frameworks to explore students' engagement with educational technologies. These include the Technology Acceptance Model (TAM) (Davis et al., 1989), the Theory of Planned Behaviour (Ajzen, 1991), Self-Determination Theory (Lee et al., 2005; Chen & Jang, 2010), and the Uses and Gratifications Model. To address the first research objective, examining the integration of the AquaInverts mobile app in an environmental education (EE) workshop, a tested and validated instrument (Camilleri and Camilleri, 2019) was adopted. Camilleri and Camilleri (2019) employed an extended Technology Acceptance Model (TAM) to explore primary school students' readiness to engage with educational mobile apps.

Camilleri and Camilleri (2019) designed a child-friendly and age-appropriate questionnaire that included eight items covering Perceived Usefulness (PU) and Perceived Ease of Use (PEoU), four items for Perceived Enjoyment (PE), three items for Normative Pressures, and three items for Behavioural Intention (BI). All items were presented on a simple three-point Likert scale with smiley-face icons to support comprehension and engagement among young learners. The researchers conducted their study on a group of 148 grade 3 children in the age range 8-9 years.

In their study, this instrument was administered to 148 children aged 8–9 and validated using exploratory factor analysis and reliability testing (Cronbach's $\alpha > 0.7$). Their results informed key hypotheses on how enjoyment and social influence relate to students' intention to use educational apps. In this study, we retained the questionnaire's four core constructs: PU, PEoU, PE, and BI were retained but adapted to reflect the specific content and ecological themes of the AquaInverts app and the EE workshop context. For instance, references to

generic "school games" were replaced with targeted items such as “The AquaInverts app was fun to use” and “I learned something new”, ensuring both relevance and clarity. The revised instrument also employed a five-point Likert scale, enhanced with expressive emojis to further support comprehension and engagement. The full adapted questionnaire is included in appendix B.

Table 3: Comparative Overview of Questionnaire Adaptation

Construct	**Example from Camilleri & Camilleri (2019)**	**Adapted Item in AquaInverts Study**
Perceived Usefulness (PU)	"The app helped me learn"	"I learned something new"
Perceived Ease of Use (PEOU)	"The app is easy to use"	"The AquaInverts app was easy to use"
Perceived Enjoyment (PE)	"The app was fun and exciting"	"The AquaInverts app was fun to use" / "…exciting to use"
Behavioural Intention (BI)	"I want to use the app again"	"I want to use the AquaInverts app again"; "I will tell others"

To ensure a robust comparative analysis between the experimental and control groups, we employed a parallel assessment strategy using adapted versions of Camilleri and Camilleri's (2019) validated questionnaire (see Appendix C). The current study uses a modified version of this instrument for the control group, tailored to assess their engagement with traditional, paper-based methods of macroinvertebrate identification. This approach aligns with best practices in educational technology research, allowing for a direct comparison of engagement levels and learning outcomes between digital and conventional instructional methods (Lai & Bower, 2019).

By maintaining consistency in the measurement framework while adapting it to each group's specific context, the current study examines the validity and reliability of our data collection process (Creswell & Creswell, 2018). This methodological choice facilitates a more nuanced understanding of the impact of the mobile app intervention on student engagement, while also enabling our results to be contextualised within the broader field of educational technology acceptance and use (Scherer et al., 2019).

Measuring Scientific Self-Efficacy in Citizen Science Contexts

To investigate research question 2, which examines how children perceive their ability to contribute reliable scientific data as citizen scientists and compares this perception between the digital (AquaInverts app) and traditional (paper-based) groups, we adapted the Citizen Science Self-Efficacy Scale (CSSES). This scale, developed and validated by Hiller and Kitsantas (2016), was designed to measure the effectiveness of citizen science programmes on student self-efficacy for scientific observation skills in nature-based learning contexts. It was developed through three empirical studies involving field experts and over 240 middle school students engaged in outdoor CS projects (e.g., monitoring horseshoe crabs).

The CSSES has demonstrated solid psychometric properties, including high internal consistency (Cronbach's α = .87–.90), and has been found to correlate significantly with established predictors of science motivation, such as task interest, outcome expectations and career goal intentions (Hiller and Kitsantas, 2016). It was initially designed for middle school students placed in outdoor, experiential contexts, but it is flexible to different educational stages and contexts, particularly when the scientific task includes real data collection and observation, which are core aspects of our workshop.

The current study adapted the CSSES to align with the context of macroinvertebrate identification and water quality monitoring, while ensuring accessibility for primary school students. Items were simplified and reworded to suit their developmental level and reflect their workshop tasks. Although the activity took place indoors, live macroinvertebrates were used to simulate field conditions and maintain scientific authenticity. In this context, scientific self-efficacy refers to students' belief in their ability to perform specific tasks required for collecting accurate environmental data, such as identifying organisms, recording observations, and supporting scientific investigations.

The CSSES was modified to fit our specific context of macroinvertebrate identification and water quality assessment. The adapted scale maintained the original structure and psychometric properties, which have been found to have high internal reliability (Cronbach's alpha = 0.89) (Hiller and Kitsantas, 2016). These aimed to ensure that the questions were appropriate for primary school students and relevant to the tasks they performed during the workshops.

The adapted CSSES was administered to both the experimental (AquaInverts app) and control (paper-based) groups after the intervention. This post-intervention design allowed the measurement of the students' self-efficacy resulting from participation in the citizen science

activity and to compare these levels between the two groups (Creswell & Creswell, 2018). By administering the scale immediately after the workshop, we capture the students' perceptions when their experience is fresh, potentially providing more accurate insights into how the different methods (digital vs. traditional) influenced their self-efficacy in scientific observation and data collection (Bonney et al., 2016).

This approach, while not allowing for a pre-post comparison, still provides valuable data on the relative impact of the two methods on students' self-efficacy. It aligns with other studies in citizen science education that have used post-intervention assessments to evaluate programme outcomes (Phillips et al., 2019). The timing of the assessment also minimises the potential for external factors to influence the students' perceptions, focusing more directly on the impact of the workshop experience (Rousell & Cutter-Mackenzie-Knowles, 2020).

The adapted scale (Appendix D) was used post-intervention on both the experimental (AquaInverts app) and control (paper-based) groups. The participants used a five-point Likert scale, presented with expressive emojis, in order to self-rate their ability to complete seven identified tasks related to scientific observer and CS participation. This approach was designed to provide data about students' immediate perceptions following the workshop and is consistent with the design employed in other CS education studies (Bonney et al., 2016; Phillips et al, 2019). This method also further reduced potential memory bias and potential external influences. The table below illustrates the adaptation process with sample items from the original CSSES and our adapted version:

Table 4: Comparison of Original and Adapted CSSES Items

Original CSSES Item (Hiller, 2016)	**Adapted Item (AquaInverts Context)**
Locate horseshoe crabs	Locate macroinvertebrates
Count horseshoe crabs	Count macroinvertebrates
Find differences between horseshoe crabs	Find differences among macroinvertebrates
Distinguish crabs from other animals	Distinguish macroinvertebrates from other animals
Write down things I see when looking at horseshoe crabs	Record macroinvertebrates
Collect data for a scientist's research study	Help scientists with data collection

Ethical Considerations

This study received ethical approval from the Ethics Committee for the School of Health and Science at Dundalk Institute of Technology (DkIT). Approval was granted on the basis that the research adhered to institutional ethical standards and that appropriate protocols were in place to protect the rights, safety, and welfare of all participants, particularly children. Relevant documentation, including the approval letter, participant information sheets, consent and assent forms, and invitation letters, is included in Appendix E.

Ethical Guidelines and Safeguards

Research ethics frameworks (BERA, 2018; Creswell & Creswell, 2018) guided the research in addressing and working through the ethical principles of informed consent, voluntary participation, right to withdraw, minimising harm and confidentiality. Specifically, when considering research with children, care was taken to ensure the activity was developmentally acceptable and free of coercion or undue influence.

All participants were informed that their involvement was voluntary, and they were assured that they could withdraw from the study at any stage without consequence. No personal or identifying information was collected during the workshops or through any of the instruments used.

Recruitment and Access

Schools were selected based on pre-existing relationships with the DkIT. Initial contact was made with school principals, who were invited to participate in the research and asked to nominate two 4th-class groups per school. Upon receiving principal approval, classroom teachers were contacted and provided with detailed information about the study. An online meeting was held with each teacher to explain the research objectives, methodology, ethical procedures, and their role in the study. In the case of Latnamard National School, due to its small rural structure, standard grade separation was not possible; instead, the school operates mixed-age classrooms. Accordingly, the nominated groups consisted of a combined 3rd and 4th class group and a combined 5th and 6th class group. This adaptation was considered appropriate within the context of the study and helped ensure the participation of rural students without compromising the research design.

Informed Consent and Assent

Two weeks prior to the workshops, all relevant documentation was sent to the participating schools. This included: A detailed workshop plan outlining the learning activities. A letter of invitation addressed to teachers, parents, and students explaining the purpose and nature of the research; A consent form for parents/guardians; An assent form for students, written in age-appropriate language; A consent form for the participating teachers. Only those students who returned signed parental consent and provided verbal and written assent were included in the study. The consent and assent forms clearly stated that participation was entirely voluntary and that students could choose not to answer any questions or to withdraw from the workshop at any point.

Role of the Teachers

Classroom teachers were not directly involved in the delivery of the research activities but remained present throughout the workshops to supervise their students and provide support as needed. Their presence helped maintain classroom routines and ensured student safety. Teachers were encouraged to ask questions about the research and were given the opportunity to decline or withdraw their participation at any time.

Data Analyses

Data analysis was organised to address the study's research questions by comparing pupils' responses across the app-based (experimental) and paper-based (control) workshop approaches. Quantitative questionnaire data were summarised using descriptive statistics (e.g., frequencies, mean scores, and standard deviations). Where items formed a scale, internal consistency was checked using reliability analysis. To support comparison between groups, conceptually matched questionnaire items were identified across the two instruments and analysed in parallel. For group comparisons on ordinal response data, non-parametric tests were used to examine whether observed differences between groups were statistically meaningful. In addition, qualitative responses (where applicable) were analysed thematically, with responses coded and grouped into themes reflecting key aspects of pupils' learning experience and engagement. Together, these analytical steps provided a structured basis for interpreting similarities and differences between the two workshop approaches.

Chapter Summary

This chapter outlined the research design and methodology used to address the study's research questions. It described the study setting and participants, the workshop procedures, and the data collection instruments used to compare app-based and paper-based approaches in a primary school EE context. It also detailed the ethical procedures and the approach used to analyse the data to support structured comparison between groups.

In interpreting the findings, it is important to acknowledge the researcher's familiarity with EE/CS contexts and prior engagement with the AquaInverts App. This familiarity may shape how the study is framed and interpreted. To mitigate potential bias, the research design and analysis followed a structured approach, using predefined instruments and consistent procedures across schools and groups, with results interpreted in direct relation to the research questions. The next chapter presents the findings from the questionnaires and related data, organised around the study's two research questions.

Chapter 4

Analyses and Findings

This chapter presents the study findings in relation to two workshop approaches designed to engage primary school pupils in EE through CS: an app-based approach using the AquaInverts App and a traditional paper-based approach. Using a quasi-experimental design and adapted instruments, the chapter compares how pupils responded to each approach in terms of engagement, perceived scientific self-efficacy, and knowledge retention. Findings are organised around the study's research questions and highlight the relative strengths and limitations of each approach in supporting participation and learning in the workshop context.

RQ1: Students' Engagement with the Activity

The first sub-research question focuses on exploring how children interact with the AquaInverts app in a workshop setting, comparing their engagement to that of those using traditional paper-based methods. To investigate the children's engagement and experience with the app, we focused on 4 dimensions: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Perceived Enjoyment (PE), and Behavioural Intentions (BI). It measured each of the dimensions with items on a 5-point Likert scale "Totally Agree - Totally Disagree", thus allowing children to articulate their subjective experience through a range of static and age-appropriate experiences.

By employing this structured engagement instrument, the study aimed to understand whether the app's interactive design enhanced learning outcomes and motivation compared to traditional methods. In the pilot study, 21 students completed the engagement questionnaire, providing valuable insights into their experiences with the AquaInverts app. The results showed a generally positive engagement, with students strongly agreeing that they learned something new (M = 4.24) and found the app's language accessible (M = 4.24).

These findings align with research suggesting that interactive educational tools can enhance learning outcomes (Camilleri & Camilleri, 2019). Enjoyment and usability scores were also positive, though slightly lower, with means of 3.86 and 3.76, respectively. However, BI items revealed more reserved responses, such as a lower willingness to download the app outside of school (M = 2.89) or share it with others (M = 3.05). This pattern highlights the need for design improvements to foster sustained engagement beyond

the classroom setting.

Taking into account the findings from the pilot study, the main phase of data collection included a substantially larger and more diverse sample of students across three primary schools. Although the AquaInverts App itself was not modified as part of this study, the workshop materials were refined following the pilot phase. In particular, the activity instructions for the app-based group were revised to provide clearer guidance at the start of the session and improved clarification on how to use the app, with the aim of supporting usability and alignment with the intended learning outcomes.

Instrument Reliability and Descriptive Statistics of the Main Study

Before the start of the analysis of the large population, again, internal reliability of the engagement scale, using the full sample from the major study, was re-evaluated. The version of the instrument used to re-examine internal reliability was unchanged from the version used in the pilot phase (Appendix 1). The reliability analysis resulted in a Cronbach's Alpha of 0.876, which indicates excellent internal consistency (Field, 2013). This supports that the scale reliably measures the intended constructs with a larger and more diverse ensemble of students.

In the experimental group, the study obtained data from 68 students from the three schools who had completed the questionnaire measuring engagement with the app. The experimental group was comprised of 35 boys (53.0%) and 31 girls (42.4%). The average age for boys was 10.74 years (SD= 0.85), with an age range of 9-12, and the average age for girls was 10.36 years (SD= 0.62), within the age range of 10-12 years old. The median age for boys was 11 years, of age and 10 years of age for girls. Overall, the boys and girls were aged appropriately with a fairly narrow age range.

To begin the analysis of student engagement with the app in the main study, we calculated descriptive statistics for the entire engagement instrument (see Table 5). The item that received the highest rating was "*I learned something new*" (M = 4.72, SD = 0.55), followed by "*I know what I am using the app for*," "*The information was interesting*," and "*The words in the app are easy*," which all received a mean score of 4.14. Usability and enjoyment items also received favourable ratings, such as "*The AquaInverts app was easy to use*" (M = 3.92) and "*The app was fun to use*" (M = 4.12). However, there were lower mean scores for the items that assessed behavioural intention, including "*I will ask permission to download (the app)*" (M = 3.12) and "*I will tell people outside the school*" (M = 3.42). As such, these lower values suggest more tentative attitudes regarding app usage outside the

classroom context.

Table : Student Engagement with the App (Main Study)

Variable	%	Mean	StDev	Min	Q1	Median	Q3	Max
I know what I am using the app	98.48	4.14	0.81	2	4	4	5	5
The App was fun to use	98.48	4.12	0.93	2	4	4	5	5
The app was exciting to use	96.97	3.91	1.06	1	3	4	5	5
The information was interesting	100.00	4.14	0.93	1	4	4	5	5
The AquaInverts app was easy to	100.00	3.92	1.14	1	3	4	5	5
The words in the app are easy	98.48	4.14	0.93	1	3	4	5	5
I want to use the app again	96.97	3.88	1.16	1	3	4	5	5
I learned something new	96.97	4.72	0.55	3	5	5	5	5
Identification of macroinvertebrates	96.97	3.84	0.93	1	3	4	4.75	5
I will ask permission to download at home	98.48	3.12	1.19	1	2	3	4	5
I will tell people outside the school about the app	98.48	3.42	1.14	1	3	3	4	5

% = Percentage; Min = Minimum; Max = Maximum; StDev = Standard Deviation

Perceived Usefulness (PU)

PU captures the degree to which students felt the AquaInverts App supported their learning and helped add meaning to the environmental education content of the workshop. This construct consisted of three items: *"I learned something new," "I know what I am using the app for*," and "*The information was interesting*." Descriptive statistics for each item are provided in Table 5. Of the three items, the statement "I learned something new" had the highest mean (M = 4.72, SD = 0.55) with a median and maximum score of 5. This suggests that the majority of students strongly agreed that the app helped them learn something new, which indicates the app seemed particularly effective in fostering learning.

The statements "*I know what I am using the app for*" and "*The information was interesting*" both recorded mean scores of 4.14, with standard deviations of 0.81 and 0.93, respectively. Median scores of 4 for both items reflect general agreement among participants. However, the broader spread of responses, including minimum scores of 1 and 2, suggests some variability in how students perceived the clarity and appeal of the app's content. Overall, these

findings indicate that students perceived the AquaInverts app as a useful educational tool for learning about environmental science and freshwater biodiversity. The consistently high ratings across all three items reinforce the app's effectiveness in delivering engaging and relevant educational material.

Table 5: Perceived Usefulness Items

Variable	Percent	Mean	StDev	Min	Q1	Median	Q3	Max
I learned something new	96.97	4.72	0.55	3	5	5	5	5
I know what I am using the app	98.48	4.14	0.81	2	4	4	5	5
The information was interesting	100.00	4.14	0.93	1	4	4	5	5

Min = Minimum; Max = Maximum; StDev = Standard Deviation

To clarity the summary statistics in Table 6, it may be useful to view the student responses visually in the form of a stacked bar chart (Figure 12).

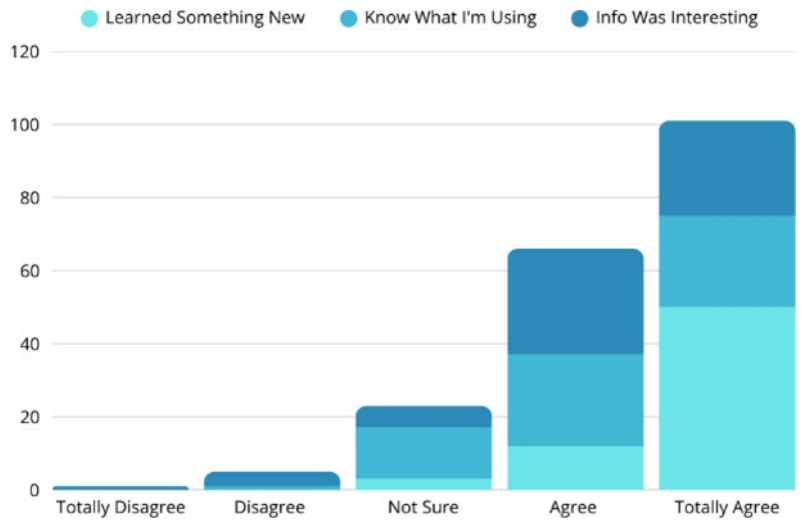


Figure 12: Distribution of Student Responses for Perceived Usefulness Items (n = 66).

The stacked bar chart presented in Figure 12 illustrates the distribution of responses to the three PU items. Overall, most students responded "Agree" or "Totally Agree" to all the items, which indicates that they perceived the app as useful. The PU item "I learned something new" had the highest level of agreement overall, with over half of the students aligning with "Totally Agree." While only a few students chose neutral or negative responses, there were also a few students who were uncertain about the PU item, "*The information was interesting*." These results imply that students viewed the app as informational and of value to their learning experience, which would facilitate the next step of analysing other usability aspects of the app, and their overall user experience.

Perceived Ease of Use (PEOU)

PEOU refers to the extent to which a person believes that a certain technology is easy to use. PEOU is one of the main constructs of the TAM (Check chapter 3) and is fundamental to understanding how users undergo evaluation of digital tools. In the context of this study, PEOU is significant because it embodies the students' perceptions of how easy it was to interact with the AquaInverts app. Three statements were used to measure this construct: "*The AquaInverts app was easy to use," "The words in the app were easy to read*," and "*Identifying macroinvertebrates was easy*". These items all reflected the overall user-friendliness of the app and its interface. It was also focused on ease of reading and ease for the students to learn using the app.

Descriptive statistics for the three items of PEOU are presented in Table 7. Overall, the responses indicate that students found the AquaInverts app accessible and easy to use. The highest mean score was recorded for the item "*The words in the app were easy*" (M = 4.14, SD = 0.93), suggesting that most students found the language and readability of the app appropriate for their age group. The item "*Identification of macroinvertebrates was easy*" also received a high mean (M = 3.84, SD = 0.93), with a median of 4 and an interquartile range from 3 to 5, indicating a positive but slightly more varied perception of task difficulty.

Lastly, the statement "*The AquaInverts app was easy to use*" showed a mean score of 3.92 (SD = 1.14), suggesting generally favourable responses regarding usability, though with slightly more variability compared to the other items. Across all three measures, the majority of students selected "Agree" or "Totally Agree," indicating that the app was broadly perceived as user-friendly and age-appropriate.

Table 6: Perceived Ease of Use Items

Variable	**Percent**	**Mean**	**StDev**	**Min**	**Q1**	**Median**	**Q3**	**Max**
The AquaInverts app was easy to use	100.00	3.92	1.14	1	3	4	5	5
The words in the app were easy to read	98.48	4.14	0.93	1	3	4	5	5
Identification of macroinvertebrates were easy	96.97	3.84	0.93	1	3	4	4,75	5

Min = Minimum; Max = Maximum; StDev = Standard Deviation

To further demonstrate the spread of responses, Figure 13 offers a stacked bar chart of the three PEOU items. While the table summarises the central tendencies, the chart provides a visual decomposition of how the student responses are reported on each item across the

five-point Likert scale and demonstrates the overall trend of positivity and the variability in ease across specific aspects of the app.

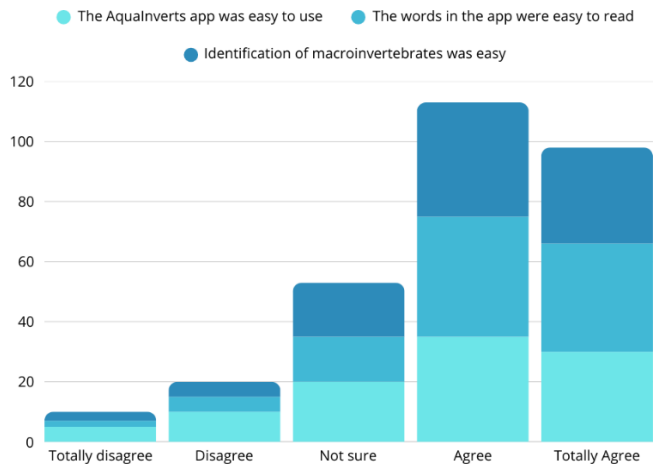


Figure 13: Stacked Bar Chart of Student Responses for Perceived Ease of Use Items (n = 66)

In general, the responses imply that students viewed the AquaInverts app as easy and manageable to use in the workshop. The highest rate of agreement was for the legibility of the app's language, followed by general usability and identifying macroinvertebrates (these responses were all "easy"). Although a small proportion of students chose unsure or disagree, most students reported positive responses, suggesting the design and usability of the app seemed appropriate for the intended age group and use context.

Perceived Enjoyment (PE)

Another important aspect of this analysis is PE. Even though PE was not included within the initial TAM, it has gained widespread recognition as an extension in research examining user engagement with educational technologies (Teo et al., 2011; Sun et al., 2006). PE refers to the extent that an individual derives pleasure or enjoyment while interacting. In the context of the current study, PE is a particularly useful framework for understanding if the AquaInverts app provided an enjoyable and stimulating learning experience for students.

Two statements were used to assess this construct: "*The AquaInverts app was fun to use*" and "*The AquaInverts app was exciting to use*." These items aimed to capture the emotional and motivational aspects of students' experiences with the app, recognising that enjoyment can significantly enhance attention, engagement, and overall learning effectiveness in environmental education settings.

The summary is presented in Table 8. Overall, students responded positively to both items, indicating that the AquaInverts app was generally seen as enjoyable and engaging. The

statement "*The app was fun to use*" received the highest mean score (M = 4.12, SD = 0.93), with the median and upper quartile values both at 4 and 5, suggesting that a majority of students agreed or strongly agreed with this statement. Similarly, the item "*The app was exciting to use*" showed a slightly lower mean of 3.91 (SD = 1.06), with responses ranging from 1 to 5.

Although the majority of students still responded positively, the slightly wider spread indicates a more nuanced experience of excitement, with some students responding with ambiguity or less excitement than others. The range of student response distribution indicates that overall, the app was perceived in a largely positive way, which supports its potential to increase motivation and engagement in EE.

Table 7: Perceived Enjoyment Items

Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
The App was fun to use	65	4.12	0.93	2	4	4	5	5
The app was exciting to use	64	3.91	1.06	1	3	4	5	5

Figure 14 illustrates the distribution of student responses to the two PE items.

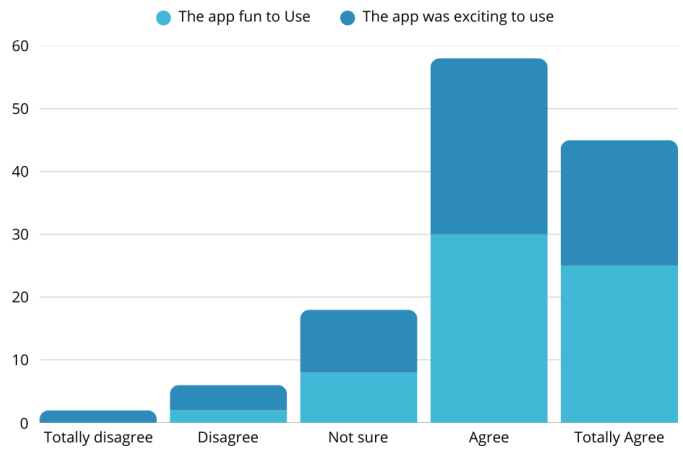


Figure 14: Responses for Perceived Enjoyment Items (n = 64– 65)

The responses suggest that students had a positive emotional experience while using the AquaInverts app. The majority agreed that the app was fun and exciting, with slightly higher ratings for overall enjoyment than for excitement specifically. While a small number of students expressed uncertainty or lower levels of enthusiasm, the distribution of responses reflects a generally favourable reception, reinforcing the app's potential to support motivation and sustained engagement in environmental learning contexts.

Behavioural Intention (BI)

The final component of the questionnaire is BI, which reflects an individual's willingness or likelihood to engage in a future behaviour, in this context, the intention to continue using the AquaInverts app beyond the workshop setting. In the TAM, BI is a critical predictor of actual technology use and is influenced by factors such as perceived usefulness, ease of use, and enjoyment. In this study, BI helps to assess whether students are likely to re-engage with the app, promote it to others, or seek opportunities to use it independently at home.

To measure this, students responded to three statements: *"I want to use the AquaInverts app again*", *"I will ask permission to download the AquaInverts app at home*" and "*I will tell people outside of school about the AquaInverts app*". These items aim to capture students' interest in sustained engagement and their openness to adopting the app outside the structured workshop environment.

As shown in Table 9, the student responses were moderately positive, with the highest mean score recorded for the statement "*I want to use the app again*" (M = 3.88, SD = 1.16). The median response for this item was 4, suggesting that many students agreed they would be willing to re-engage with the app in future learning contexts. The second statement, "*I will tell people outside the school about the app*," received a lower but still positive mean score of 3.42 (SD = 1.14), with the median at 3. This suggests that while some students were enthusiastic about promoting the app, others were more neutral or uncertain.

The lowest mean score was observed for "*I will ask permission to download the app at home*" (M = 3.12, SD = 1.19), with a median of 3. This indicates that although some students expressed interest in using the app independently, others were hesitant or lacked motivation to use it outside a school setting. These results reflect varied levels of behavioural intention, with the strongest interest centred on continued use within the classroom context.

Table 8: Behavioural Intention Items

Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
I want to use the app again	64	3.88	1.16	1	3	4	5	5
I will ask permission to download	65	3.12	1.19	1	2	3	4	5
I will tell people outside the	65	3.42	1.14	1	3	3	4	5

The stacked bar chart in figure 15 helps to clarify the varying levels of agreement and highlights differences in students' intentions to continue using or promoting the app beyond the workshop setting.

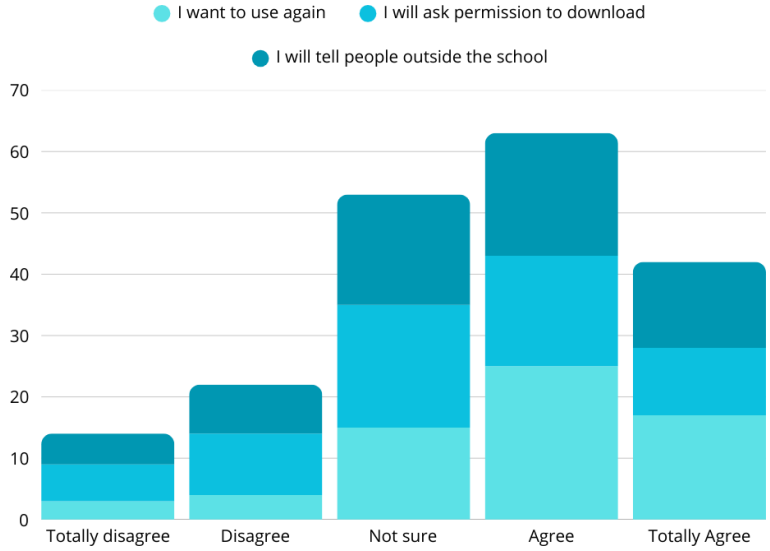


Figure 15**:** Stacked Bar Chart of Student Responses for Behavioural Intention Items (n = 64– 65)

Finally, it should be noted that the findings related to BI suggest that while students were generally open to re-engaging with the AquaInverts app, their willingness to extend its use beyond the classroom was more varied. The strongest intention was expressed for future in-school use, whereas fewer students indicated a clear desire to download the app at home or promote it to others. These mixed findings emphasised context as a factor shaping BI. It appears the app effectively supplemented classroom learning, but additional approaches may be needed to stimulate interest/concept building in more open contexts.

From the Pilot to the Main Study

A quick comparison of student feedback from the pilot group (n = 21) and the main study group (n = 66) suggested positive response patterns on all four engagement factors. In the PU scale, mean scores for the main group increased slightly, indicating students had a

stronger agreement with the statement that "I learned something new" demonstrating better planning, clarity, and learning after making workshop refinements. For PEOU, students in both groups reported that the app was easy to use, with a slight increase from the pilot to the main study group, particularly regarding readability of the text. The mean scores for PE also showed a slight increase in the main study group, suggesting a stronger emotional connection to the work after the adjustments prior to the main study.

Lastly, BI responses remained moderately positive in both samples, with a small increase in students expressing willingness to use the app again, though intentions to promote or download it remained mixed. Overall, the consistency between groups supports the reliability of the refined engagement instrument and suggests improved student experience in the full implementation.

RQ1: Assessing Engagement Without the AquaInverts App

To assess children's engagement with the traditional, non-digital method of identifying macroinvertebrates, we adapted an evaluation instrument originally based on Camilleri and Camilleri's (2019) questionnaire (see appendix 2). Although the original instrument was developed within the framework of the TAM, this questionnaire was modified to suit the context of the control group, which did not use the AquaInverts app. The revised instrument aimed to capture key aspects of the students' experience with the paper-based identification guide, focusing on enjoyment, clarity, and perceived learning, similar to the TAM. This comparison forms part of a broader objective to evaluate which method, digital or traditional, more effectively engages children in environmental science activities.

Control Group (Pilot)

Within the control group pilot, 21 students (n = 21) completed the post-workshop evaluation; this group consisted of 11 boys and 10 girls. Instrument development and adaptation are described in Chapter 3. Internal consistency for the pilot control-group engagement scale was acceptable (Cronbach's alpha = 0.731) (Field, 2013). Responses were recorded on a five-point Likert scale, and descriptive statistics were computed for each item.

Students reported high levels of enjoyment and perceived learning. The highest-rated item was "It was exciting" (M = 4.71, SD = 0.56), closely followed by "I would like to do it again" (M = 4.62) and "I learned something new" (M = 4.60), suggesting strong emotional and cognitive engagement with the activity in the workshop.

Other items, such as "*The identification was fun*" and "*The information was*

interesting", also received high ratings, indicating that the paper-based method was positively received. Although engagement levels were generally strong, slightly lower scores were recorded for "*Identification of macroinvertebrates was easy*" (M = 3.90) and "*I will tell people outside the school about the workshop*" (M = 3.76), suggesting some variability in how accessible or share-worthy students found the experience.

Building on the insights gathered during the pilot, the engagement instrument was preserved for the main study, making slight wording tweaks for clarity. While the pilot study results found the students enjoyed and were interested in using the traditional method of identifying macroinvertebrates. The initial results reinforced continuing to use the instrument in the larger sample of the control group. Next, we present the analysis of the engagement in the control group sample, to provide more detail and a stronger understanding of students' engagement with the traditional paper-based activity across school settings.

Control Group in the Main Study

The control group in the main intervention comprised 77 students (n=77) across three schools. Of these, 36 were boys (46.8%), and 41 were girls (53.2%). The overall age range was between 9 and 11 years. Boys had a slightly higher mean age of 10.28 years (SD = 0.51), while the mean age for girls was 10.05 years (SD = 0.59). The median age for both groups was 10 years, reflecting a relatively balanced and age-appropriate sample for the study's intended learning outcomes.

Instrument Reliability (Main Control Group)

Cronbach's Alpha was calculated to determine the internal consistency of the questionnaire used with the main control group. The resulting $\alpha = 0.7703$ indicates an acceptable level of reliability (Field, 2013). This suggests the items in the adapted questionnaire consistently measured the aspects of student engagement during the traditional activity. The reliability supports the continued use of the instrument

Descriptive Analysis: Control Group Engagement (Main Study)

The control group (n = 77) demonstrated strong levels of engagement with the macroinvertebrate identification task using the paper guide, as shown in Table 10. The more positively endorsed items included *"I learned something new"* (M = 4.67, SD = 0.64) and "*I would like to do it again"* (M = 4.65, SD = 0.84), indicating a strong interest and learning associated with the task. Participants also reported recreation and enjoyment engagement for items such as "*It was exciting*" (M = 4.50) and "*The identification was fun*" (M = 4.44).

Cognitive engagement was further demonstrated with a high endorsement of "*The information was interesting*" (M = 4.45). Usability-related items, including "*The guide was easy to follow"* (M = 4.04), and "*The words are easy to read"* (M = 4.00) garnered positive responses but showed a little lower than usual.

Table 9: Group Responses to Traditional Identification Activity

Variable	N	Percent	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
The identification was fun	77	100.00	4.44	0.80	1	4	5	5	5
It was exciting	76	98.70	4.50	0.79	1	4	5	5	5
The information was interesting	76	98.70	4.45	0.60	3	4	4.5	5	5
The guide was easy to follow	75	97.40	4.04	0.81	2	3	4	5	5
The words are easy to read	76	98.70	4.00	0.94	2	3	4	5	5
I would like to do it again	72	93.51	4.65	0.84	1	5	5	5	5
I learned something knew	76	98.70	4.67	0.64	2	4.25	5	5	5
Identification of macroinvertebrates	76	98.70	3.41	0.95	1	3	3	4	5
I will tell people outside the	76	98.70	4.13	0.90	1	3.25	4	5	5

The lowest-rated item was "*Identification of macroinvertebrates was easy*" (M = 3.41, SD = 0.95), suggesting that some students may have experienced difficulty with this aspect of the activity. Nonetheless, the item "*I will tell people outside the school about the workshop*" received a moderately strong score (M = 4.13), indicating a willingness among students to share their experience beyond the classroom.

Categorisation of Control Group Responses

To analyse student engagement in the control group, the questionnaire items were grouped into five overarching categories that reflect key aspects of the learning experience: *Enjoyment & Excitement*, *Perceived Learning*, *Usability and Task Difficulty*, and

Re-engagement & Sharing. We created these categories similar to TAM and based on the content of each item allowing for a more meaningful interpretation of the students' responses. Descriptive statistics for each theme are summarised below, along with visual representation.

Enjoyment & Excitement

Within this theme we aim to captures students' emotional responses to the traditional macroinvertebrate identification activity, focusing on enjoyment and excitement. As shown in Table 11, students reported high levels of enjoyment when identifying macroinvertebrates using the traditional method. The item "*The identification was fun*" received a mean score of 4.44 (SD = 0.80), while "*It was exciting*" was rated slightly higher, with a mean of 4.50 (SD = 0.79). In both cases, the median score was 5, and the upper quartile (Q3) was also 5, suggesting that at least 75% of students agreed or strongly agreed that the activity was enjoyable and engaging.

Table 10: Enjoyment and Excitement Items in the Control Group

Variable	N	Percent	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
The identification was fun	77	100.00	4.44	0.80	1	4	5	5	5
It was exciting	76	98.70	4.50	0.79	1	4	5	5	5

The low standard deviations reflect consistent positive responses across the sample, and the high response rates (100% and 98.7%, respectively) confirm the relevance and accessibility of the items for participants. These findings suggest the success of the activity in generating emotional engagement and sustaining student interest throughout the workshop. To further illustrate the distribution of student responses related to enjoyment, Figure 16 presents a stacked bar chart comparing the items *"The identification was fun*" and "*It was exciting*."

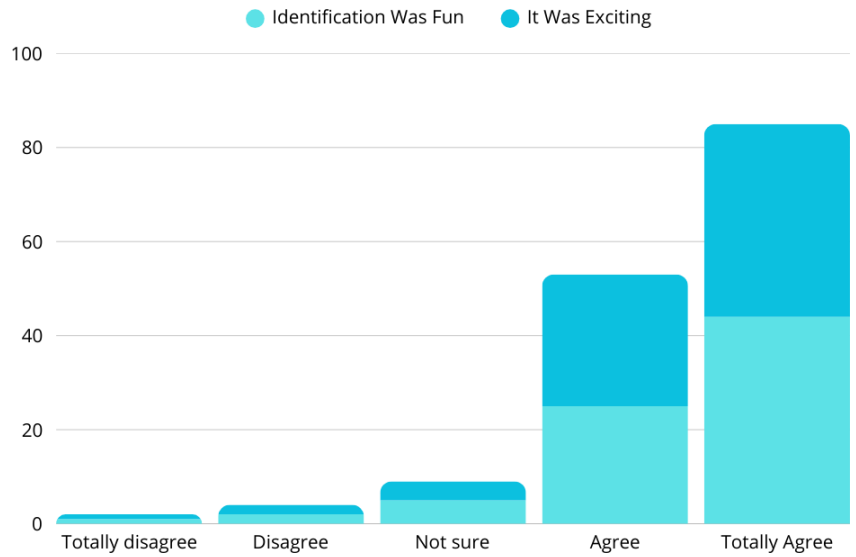


Figure 16: Student responses to enjoyment-related statements in the control group.

The data in Figure 16 indicate that most students selected either "Agree" or "Totally Agree" for both enjoyment-related items, suggesting high enjoyment of the traditional identification activity in the control group. The item "*The identification was fun*" received slightly more "Totally Agree" responses than "*It was exciting*", which received relatively more "Agree" responses. Very few students selected "Disagree" or "Totally disagree", and only a small number selected "Not sure". Overall, the pattern in Figure 16 aligns with the descriptive statistics reported above and reinforces the finding that enjoyment ratings were high among control-group pupils.

Perceived Learning

Perceived learning is concerned with how students self-reported feeling they learned something new and that their involvement in the workshop had value. In this context, it describes how effective the traditional way of identifying macroinvertebrates was in helping to support students' environmental literacy and engagement. This theme is especially relevant to addressing the educational potential of non-digital, experiential learning experiences. Students were asked to reflect on whether they felt they learned something new, and whether the information presented in the workshop was interesting and engaging.

Table 12 presents the descriptive statistics for the two items related to perceived learning within the control group. Students responded very positively, with the statement "*I learned something new*" receiving the highest average score (M = 4.67, SD = 0.64) and a median of 5, indicating that most participants strongly agreed with the statement. The item "*The information was interesting*" also showed a high level of agreement, with a mean of

4.45 and a median of 4.5. The consistently high scores across both items suggest that the traditional
identification activity was successful in fostering new learning and sustaining student interest in environmental content.

Table 11: Perceived Learning Items – Control Group

Variable	N	Percent	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
I learned something knew	76	98.70	4.67	0.64	2	4.25	5	5	5
The information was interesting	76	98.70	4.45	0.60	3	4	4.5	5	5

Figure 17 Illustrates the students' responses to items on perceived learning. The vast majority selected "Agree" or "Totally Agree", especially for the item "*I learned something new*", where responses were heavily concentrated at the highest scale point. This reflects a strong consensus that the traditional identification activity was effective in enhancing their understanding. Similarly, "*The information was interesting*" also showed high levels of agreement. Only a small number of students expressed uncertainty or disagreement, reinforcing the conclusion that the activity was both educational and engaging.

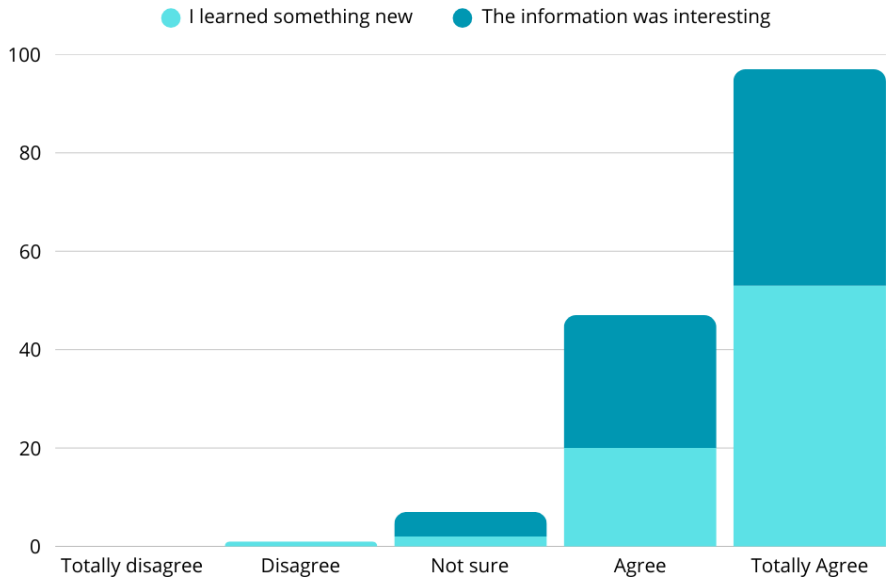


Figure 17: Distribution of student responses to perceived learning items in the control group (n = 76).

Usability and Task Difficulty

The perceived the clarity and accessibility of the paper-based identification method used in the workshop. Items focused on the readability of the materials, clarity of the guide, and the perceived difficulty of identifying macroinvertebrates. These aspects help evaluate the usability of the traditional tools and how easily students can complete the activity.

As shown in Table 13, most students reported positive experiences with the usability of the paper-based materials. Both “The guide was easy to follow” and “The words are easy to read” received a mean rating of approximately 4.00, with medians of 4, indicating that students generally found the materials accessible and clearly presented. However, the item “Identification of macroinvertebrates was easy” had a lower mean of 3.41 and a median of 3, suggesting that some students found the actual identification process more challenging. This contrast highlights that while instructions were largely clear, the task of identifying species may have required more support or clearer cues in the traditional format.

Table 12: Usability and Task Difficulty Items – Control Group

Variable	N	Percent	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
The guide was easy to follow	75	97.40	4.04	0.81	2	3	4	5	5
The words are easy to read	76	98.70	4.00	0.94	2	3	4	5	5
Identification of Macroinvertebrates was easy	76	98.70	3.41	0.95	1	3	3	4	5

As shown in Figure 18, the vast majority of the students provided affirmative responses to the three items associated with usability and task difficulty. Overall, most students selected either "Agree" or "Totally Agree" to the two items that read "*The guide was easy to follow*" and "The words were easy to read." The item "*Identification of macroinvertebrates was easy"* had more variability in responses, with a notable proportion of students selecting "Not Sure" and fewer selecting "Totally Agree" than for the previous two items. Overall, the distribution of students' responses indicates that most students had a positive experience, though there was some uncertainty related to the actual identification task.

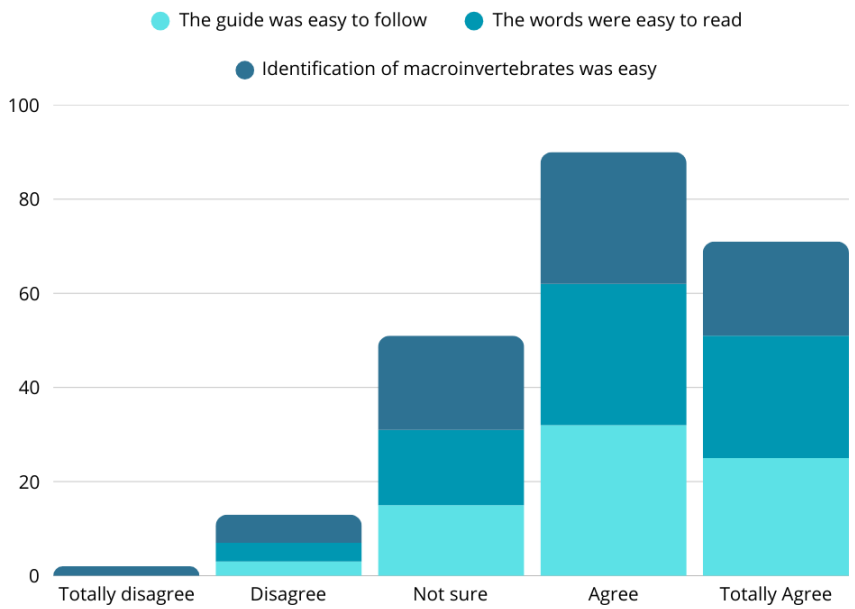


Figure 18: Students' responses to items related to usability and task difficulty in the traditional method.

Re-engagement and Sharing

Further question explores the students' willingness to re-engage with the traditional macroinvertebrate identification activity in the future and their intentions to share their experiences beyond the classroom. These responses provide insight into the extent to which the activity fostered lasting interest and personal relevance. The following items focused on whether students would like to participate in a similar workshop again and if they intended to tell others about the activity. As shown in figure 19.

The statement about "*I would like to do it again*" achieved the highest overall mean (M = 4.65), and the median was 5, which indicates a high likelihood that the participants were interested in doing the traditional macroinvertebrate activity again. For the statement "*I will tell people outside of this workshop*", there was slightly more variability (M = 4.13), but still indicates a generally positive attitude toward sharing the experience with others outside the fishing class. Overall, these data indicate high levels of enthusiasm and interest in continuing with the topic after the workshop.

Table 12: Re-engagement & Sharing Items (Control Group)

Variable	N	Percent	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
I would like to do it again	72	93.51	4.65	0.84	1	5	5	5	5
I will tell people outside the school	76	98.70	4.13	0.90	1	3.25	4	5	5

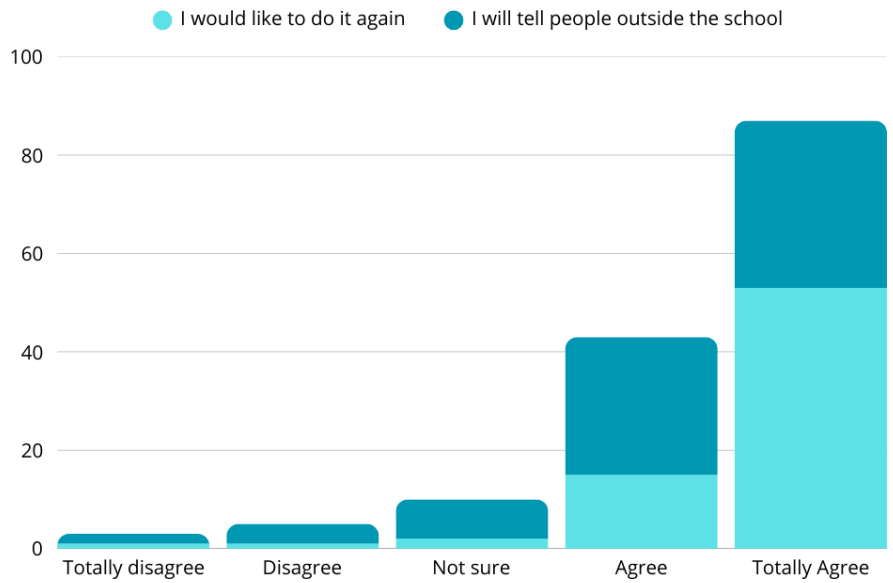


Figure 19: Students' responses to re-engagement and sharing items in the control group.

As shown in Figure 19, the majority of students in the control group selected "Agree" or "Totally Agree" for both items related to re-engagement and sharing. The highest level of agreement was observed for the statement "*I would like to do it again*", with over half of the responses falling under "Totally Agree." Responses to "*I will tell people outside the school*" also showed a generally positive trend, though with a slightly more even distribution across the response scale. Very few students selected negative options, indicating an overall favourable response to the traditional identification activity.

With the analyses of the experimental and control groups whole instruments conducted, we now have a clear picture of students' experiences within the workshop using different approaches to identify macroinvertebrates. This preliminary understanding provides an important contextual foundation with respect to engagement, perceived learning, usability, and engagement and re-engagement.

To further understand how they performed relative to one another in practice, the next section will provide inferential analyses to assess any statistically significant differences between groups. These measures will indicate the relative strengths of the AquaInverts app as

compared to a traditional paper-based approach related to experiences regarding engagement and learning.

Comparative Analysis of Student Engagement: App vs. Traditional Method (RQ1)

To explore how children perceive and interact with different tools for within the worshop, this section presents a comparative analysis between the experimental group and the control group. While the two groups experienced different modes of identify macroinvertebrates, several items in the questionnaires post-workshop were conceptually aligned, allowing for meaningful comparisons across key themes such as enjoyment, learning, usability, and behavioral intention. The aim of this comparative analysis is to consider which method more strongly stimulated students' engagement, supported learning, and encouraged motivation to continue the experience. Exploring matched items across both questionnaires will ultimately provide the ability to quantify differences in student perceptions and to reach conclusions on the relative effectiveness of digital and traditional tools in an educational workshop context.

To facilitate meaningful statistical comparisons between the experimental and control groups, only questionnaire items that were conceptually equivalent across both instruments were selected. Although the wording varied slightly to reflect the digital or traditional context, each pair of items measured the same underlying construct related to student engagement, learning, usability, and behavioural intention. Table 14 presents an overview of the matched items used in this analysis, organised by theme. These aligned items provided the foundation for the subsequent independent samples t-tests, which were used to determine whether there were significant differences in how students experienced and responded to each workshop format.

Table 13: Matched Questionnaire Items for Experimental and Control Groups

Theme	Experimental Group (App)	Control Group (Traditional)
Enjoyment	The app was fun to use	The identification was fun
Excitement	The app was exciting to use	It was exciting
Perceived Usefulness	I learned something new	I learned something new
Interest	The information was interesting	The information was interesting
Usability – Readability	The words in the app are easy	The words are easy to read
Usability – Ease	Identification of macroinvertebrates was easy	Identification of macroinvertebrates was easy
Intention to Reuse	I want to use the app again	I would like to do it again
Sharing Intention	I will tell people outside the school about the app	I will tell people outside the school

Before diving into each theme in detail, Table 15 presents a summary of student responses from both the experimental group and the control group (Items are grouped by thematic focus, and the table includes the mean scores for each group along with the difference in means. This overview provides a foundation for understanding the broader engagement patterns across the two instructional approaches.

Table 14: Comparative Overview of Engagement Between Groups

Theme	Experimental (M)	Control (M)	Difference
Enjoyment	4.12	4.44	-0.32
Excitement	3.91	4.50	-0.59
Learning	4.72	4.67	+0.05
Information	4.14	4.45	-0.31
Readability	4.14	4.00	+0.14
Task Difficulty	3.84	3.41	+0.43
Intention to Reuse	3.88	4.65	-0.77
Sharing	3.42	4.13	-0.71

Enjoyment

A Two-Sample Equivalence Test was used to examine whether enjoyment ratings for the AquaInverts App and the traditional paper-based activity could be considered practically comparable, rather than simply testing for a difference between groups. In other words, this approach evaluates whether the observed difference in mean scores falls within an a priori equivalence range (i.e., a difference small enough to be considered negligible in practice). The mean enjoyment score for students using the traditional identification method (M = 4.44, SD = 0.80, n = 77) was higher than the mean score for students using the AquaInverts App (M = 4.12, SD = 0.93, n = 65). Table 16 provides descriptive statistics.

Table 15: Descriptive statistics for enjoyment scores by group

Group	N	Mean	StDev	SE Mean
Control	77	4.44	0.80	0.091493
Experimental	65	4.12	0.93	0.11500

The observed mean difference was 0.32 (SE = 0.15), with a 95% confidence interval of (0.075, 3.00). However, this interval does not lie within the pre-defined equivalence bounds of (1, 5), indicating that statistical equivalence cannot be claimed. These results are summarised in Table 17.

Table 16: Two-sample equivalence test for enjoyment

Difference	SE	95% CI for Equivalence	Equivalence Interval
0.32	0.15	(0.07, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Although both groups reported high enjoyment scores, the control group experienced statistically greater enjoyment, and the difference between groups is considered meaningful based on the test outcome.

Excitement

Beyond enjoyment, excitement is an important variable in keeping learners engaged and curious while doing activities that involve learning something. This part describes the level of excitement reported by students while using the AquaInverts in comparison to the students who participated in a traditional macroinvertebrate identification. Both groups were involved in hands-on exploration, but we were hoping to assess whether the digital, app-based model provided a more stimulating and emotionally engaged experience than the traditional macroinvertebrate taxonomical experience.

The control group reported a greater mean level of excitement (M = 4.50, SD = 0.79, n = 76) compared to the experimental group (M = 3.91, SD = 1.06, n = 64). The difference in means was 0.594 (SE = 0.161). Even though both groups reported high levels of excitement, the control group had a statistically higher level of excitement than the app group.

Table 17: Comparison of Excitement Levels Between Groups

Group	N	Mean	StDev	SE Mean
Control	76	4.50	0.79	0.090805
Experiment	64	3.91	1.06	0.13311

Difference	SE	95% CI for Equivalence	Equivalence Interval
0.59	0.16	(0.33, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Perceived Usefulness

Using the item, "I learned something new," we aim to evaluate students' perceived educational value of the activity to test for equivalence between groups. The control group had a mean of 4.67 (SD = 0.64, n = 76), while the experimental group had a mean of 4.72 (SD = 0.55, n=64) (see Table 20). A Two-Sample Equivalence Test was conducted to determine if groups can be treated as being statistically equivalent with respect to their perceived educational value.

The observed mean difference is -0.048 (SE = 0.100), with a 95% confidence interval of -0.214 to 3. Since this confidence interval does not include the pre-defined equivalence bounds of 1 to 5, we are unable to conclude that the groups were statistically equivalent. The means are similar, and both groups rated their experience equally, but statistically, the differences, even if small, should not be considered negligible, and equivalence cannot be accepted given the equivalence bounds. Despite students in both groups perceiving the activity as educational, the data do not substantiate that students perceived the educational value of the activity to be equivalent.

Table 18: Comparison of Perceived Usefulness Between Control and Experimental Groups

Group	**N**	**Mean**	**StDev**	**SE Mean**
Control	76.00	4.67	0.64	0.073480
Experiment	64.00	4.72	0.55	0.068533

Difference	**SE**	**95% CI for Equivalence**	**Equivalence Interval**
-0.05	0.10	(-0.21, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Interest

To assess students' perception of the value of the hands-on activity, both groups responded to the statement: "The information was interesting." This prompt was utilised to assess the students' level of engagement and attention prompted by the educational content. The control group rated their average interest level higher than the experimental group, with the traditional group (M = 4.45, SD = 0.60, n = 76) rating higher than the experimental group (M = 4.14, SD = 0.93, n = 66). A Two-Sample Equivalence Test was used to determine if a difference existed across groups.

The observed mean difference from Table 20 was 0.31 (SE = 0.13) with a 95% confidence interval of (0.090, 2.745). Since the confidence interval did not fall squarely within the predetermined equivalence range of 1 to 5, equivalence could not be claimed. From these results, we can conclude that students found the information engaging, but the control group rated the experience significantly more interesting than the experimental group.

Table 19: Descriptive and Equivalence Test Statistics for "The Information Was Interesting" in Control and Experimental Groups

Group	N	Mean	StDev	SE Mean
Control	76	4.45	0.60	0.068556
Experiment	66	4.14	0.93	0.11402

Difference	SE	95% CI for Equivalence	Equivalence Interval
0.31	0.13	(0.09, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Usability – Readability

The control group had a mean score of 4.00 (SD = 0.94, n = 76), while the experimental group reported a slightly higher mean of 4.14 (SD = 0.93, n = 65). The mean difference was -0.14 (SE = 0.16), with a 95% confidence interval of -0.40 to 3.00. The equivalence test subsequently demonstrated that the confidence interval does not fall within the specified equivalence range of 1 to 5 and therefore, equivalence across groups cannot be inferred. This indicates that while the groups both rated the readability positively, their responses were not statistically equivalent based on the criteria for the equivalence test.

Table 20: Comparison of Perceived Readability Between Control and Experimental Groups

Group	N	Mean	StDev	SE Mean
Control	76	4.00	0.94	0.10761
Experiment	65	4.14	0.93	0.11577

Difference	SE	95% CI for Equivalence	Equivalence Interval
-0.14	0.16	(-0.40, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Usability – Ease

The control group had a mean score of 3.41 (SD = 0.95, n = 76) compared to the experimental group's mean of 3.84 (SD = 0.93, n = 64). The observed mean difference was -0.44 with a standard error (SE) of 0.16, with a 95% confidence interval of -0.70, 3.00. However, this confidence interval did not fall within the established equivalence range of 1 through 5; therefore, equivalence could not be claimed between the groups. While both groups generally agreed that the task was easy to complete, the data suggest that the app-based activity used to identify macroinvertebrates was perhaps deemed to be slightly easier to use.

Table 21: Two-Sample Equivalence Test for Usability – Ease of Identification Between Experimental and Control Groups

Group	**N**	**Mean**	**StDev**	**SE Mean**
Control	76	3.4079	0.95467	0.10951
Experiment	64	3.8438	0.92956	0.11620

Difference	**SE**	**95% CI for Equivalence**	**Equivalence Interval**
-0.43586	0.15967	(-0.700299, 3)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Intention to Reuse

To examine students' willingness to reuse the identification activity, a Two-Sample Equivalence Test was performed comparing the control group and the experimental group. Higher mean scores were obtained in the control group (M = 4.65, SD = 0.84, n = 72) than the experimental group (M = 3.88, SD = 1.16, n = 64). The difference between means was 0.778 (SE = 0.176), and the 95% confidence interval ranged from 0.486 to 3.00. The difference is greater than the previously agreed-upon equivalence bounds (1 - 5). Thus, we cannot claim a statistical equivalence. Students in the traditional group had a greater intention to reuse the opportunity compared to the experimental group, and this difference was more than trivial.

Table 22: Descriptive and Inferential Statistics for Intention to Reuse Activity

Group	**N**	**Mean**	**StDev**	**SE Mean**
Control	72	4.6528	0.84186	0.099214
Experiment	64	3.8750	1.1616	0.14519

Difference	SE	95% CI for Equivalence	Equivalence Interval
0.77778	0.17585	(0.486132, 3)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

Sharing Intention

Lastly, to assess students' intention to share their experience beyond the classroom, an equivalence test was conducted. The control group had a higher average score reported (M = 4.13, SD = 0.90, n = 76) than the experimental group (M = 3.42, SD = 1.14, n = 65). The mean difference between groups was 0.72 (SE = 0.18) with a 95% confidence interval ranging from 0.43 to 3.00. As with the previous comparisons, the confidence interval still falls outside of the predetermined equivalence range of 1 through 5. Therefore, statistical equivalence cannot be claimed between groups. This indicates that there was a significant difference in students' intent to share their experience, indicating the control group demonstrated a greater intent to share as compared to app users.

Table 23: Equivalence Test for Sharing Intention Between Experimental and Control Groups

Group	**N**	**Mean**	**StDev**	**SE Mean**
Control	76	4.13	0.90	0.10318
Experimental	65	3.42	1.14	0.14192

Difference	**SE**	**95% CI for Equivalence**	**Equivalence Interval**
0.72	0.18	(0.43, 3.00)	(1, 5)

CI is not within the equivalence interval. Cannot claim equivalence.

In summary, the analysis revealed that both the digital (AquaInverts app) and traditional (paper-based) methods successfully supported student engagement and learning in environmental science. While the app was rated highly for PU and PUoE, the traditional method yielded stronger emotional engagement and a higher intention to reuse the activity. Regarding scientific self-efficacy, both groups demonstrated confidence in their ability to contribute to citizen science tasks, with notable differences in specific skill areas such as data recording and macroinvertebrate description. These findings offer a comprehensive baseline for interpreting the educational value and practical implications of each approach, which will be further explored in the next chapter.

Research Question 2 shifts attention from engagement to scientific self-efficacy, exploring how confident students felt in their capacity to contribute to authentic scientific practices as young citizen scientists. The following section presents the results of the adapted CSSES, offering comparative insights between the experimental and control groups.

RQ2 – Students' Ability to Contribute to Science

One One of the main benefits of Citizen Science (CS) programmes for children is that they offer valuable opportunities to engage with real-world scientific processes, enhancing not only knowledge but also confidence and a sense of participation. Research Question 2 examined how the workshop influenced pupils' perceived ability to contribute reliable scientific information as citizen scientists, and whether this differed between the AquaInverts (digital) and paper-based (traditional) approaches. To address this question, pupils completed an adapted version of the Citizen Science Self-Efficacy Scale (CSSES) developed by Hiller and Kitsantas (2016).

Self-efficacy, as defined by Bandura (1997), plays a pivotal role in shaping motivation and sustained engagement, particularly within inquiry-driven educational settings. This version was tailored to reflect tasks specific to the identification and documentation of macroinvertebrates within the workshop context. Pupils were asked to rate how well they believed they could perform key CS tasks (e.g., locating, counting, and identifying macroinvertebrates, and assisting with data collection). The full questionnaire is provided in Appendix D.

In the scale, the responses were captured using a five-point qualitative scale: "Not at all," "A little," "Not sure," "Well," and "Very well." To enable statistical analysis, these responses were numerically coded from 1 to 5, respectively, where 1 represented the lowest level of perceived ability and 5 the highest. This coding process allowed for the calculation of descriptive statistics and inferential tests to compare perceived scientific contribution between the experimental and control groups.

Reliability Analysis and Descriptive Statistics of CSSES– Experimental Group (Main Study)

Before the main analyses, we first looked at the internal consistency of the adapted CSSES in the main experimental group; responses from 65 students were analysed. The scale showed strong internal consistency, with a Cronbach's Alpha of 0.8937, indicating high reliability. Correlation across items varied from moderate to high, especially for "Describe different macroinvertebrates" and "Find differences among macroinvertebrates" ($r = 0.682$), which indicated conceptual agreement amongst similar tasks. Thus, we can conclude that these results validate applying the scale in measuring the perceived science contribution of the

students in this workshop.

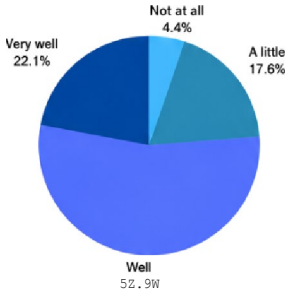
In Table 25, students showed relatively high confidence across all items analysed, with mean scores ranging from 3.64 to 3.94. The highest average rating was for the item "Find differences among macroinvertebrates" (M=3.94, SD = 0.93), closely followed by "Locate macroinvertebrates" (M = 3.90, SD = 0.92). The lowest mean was observed for "Distinguish macroinvertebrates" (M = 3.64, SD = 1.08), indicating slightly more variability in perceived ability. Medians across all items were consistently 4 (“Well”), with third quartiles reaching 5, reflecting a generally strong sense of good ability among students using the AquaInverts app within the workshop.

Table 24: Students’ Perceived Scientific Abilities – Experimental Group (Main Study)

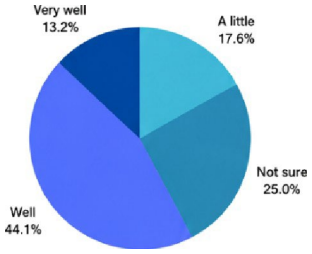
Variable	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Locate Macroinvertebrates	3.90	0.92	1	4	4	4	5
Count Macroinvertebrates	3.69	0.97	2	3	4	4	5
Describe different macroinvertebrates	3.75	0.88	2	3	4	4	5
Find differences among macroinvertebrates	3.94	0.93	2	3	4	5	5
Distinguish macroinvertebrates	3.64	1.08	1	3	4	5	5
Record macroinvertebrates	3.72	1.04	1	3	4	5	5
Help Scientists with data collection	3.76	0.97	1	3	4	5	5

To complement the descriptive statistics, the following pie charts to illustrate students' self-perceived capacity to participate in scientific activities in the experimental group. By displaying the percentage of each item that students rate, each chart provides a clearer picture of how confident students felt performing particular scientific tasks. Each chart breaks down responses for one of the seven assessed tasks. The statistical results are given more depth by this visual representation, which also reveals trends in perceived ability at different phases of the macroinvertebrate identification and data gathering procedure.

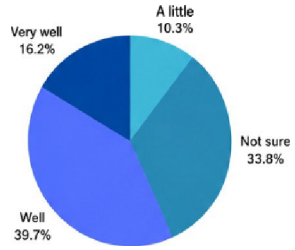
Locate Macroinvertebrates



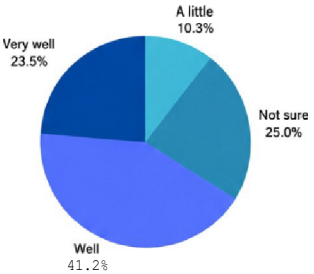
Count Macroinvertebrates



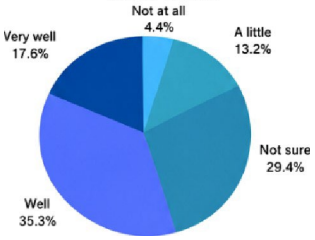
Describe DiWerent Macroinvertebrates



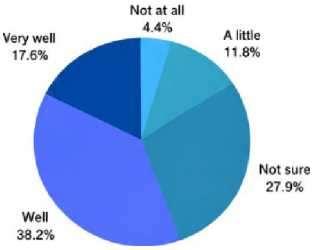
Find Differences in Macroinvertebrates



Distinguish Macroinvertebrates from Other Animals



Record Macroinvertebrates



Help Scientists with Data Collection

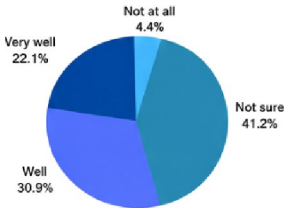


Figure 20: Self-perceived ability to perform citizen science tasks among students in the experimental group using the AquaInverts app.

As shown in Figure 20, although differences in confidence levels suggest that some skills might require more support or instructional focus, the data overall indicate a positive perception across all seven skill areas by the students. With 52.9% selecting "Well" and 22.1% selecting "Very well," most students felt confident in their ability to “locate macroinvertebrates”. This high combined percentage (75%) suggests that the app's interactive and visual features may have supported students in mastering this fundamental step. Fewer respondents (17.6%) chose "Not sure", and even fewer (4.4%) selected "Not at all," indicating that the app was generally effective in making this task easier.

The data indicate a slight decrease in confidence for the task in the category of “count macroinvertebrates”. About 25% said they were "not sure," and 17.6% said they could only do it "a little," despite 44.1% saying they could do it "well" and 13.2% saying they could do it "very well." This implies that although a large number of students felt at ease with counting, others might have had trouble with accuracy or comprehending the significance of accurate enumeration. The distribution became more evenly distributed when it came to the category “describe different macroinvertebrates”. Just 39.7% of respondents said they could do so "Well," 16.2% said they could do so "Very well," and 33.8% said they were "Not sure." The comparatively high level of uncertainty could be a result of having trouble using the right terminology or expressing noticeable differences. The 10.3% who selected “A little” indicates a portion of students had limited confidence in this descriptive task.

The category “find differences in macroinvertebrates” had a comparatively high level of confidence, with 41.2% choosing "Well" and 23.5% choosing "Very well,". The app appears to have supported comparative observation well, based on the high ratings in this analytical skill. Nonetheless, 25% of students still chose "Not sure," suggesting that some might need more structured instruction or scaffolding when it comes to differentiating

between them. The data showed somewhat lower confidence in the task of “differentiating macroinvertebrates from other animals”. Nearly 30% said they were "Not sure," while 35.3% said they could do it "Well" and 17.6% said they could do it "Very well." It appears that differentiating macroinvertebrates from non-target organisms was not always easy, as evidenced by the 13.2% who selected "A little" and the 4.4% who selected "Not at all." This could be explained by the difficulty of the classification process or the lack of comparison examples.

Confidence levels in the category of “record macroinvertebrates” declined further when it came to data recording: 38.2% said they did it "Well," 17.6% said they did it "Very well," 27.9% said they were "Not sure," and 16.2% chose "A little" or "Not at all." These findings demonstrate that although students might be able to observe macroinvertebrates, they are unsure about formally recording their observations, which is an essential citizen science ability. Finally, there was the greatest degree of uncertainty in the final task, which was designed to gauge the self-confidence of “help scientists with data collection”, with 41.2% of respondents choosing "Not sure." Just 22.1% thought they could do it "Very well," and only 30.9% thought they could do it "Well." Students' limited comprehension of what scientific data collection involves or their belief that it necessitates expert knowledge beyond their current capabilities may be the cause of the high percentage of unsure responses. Just 4.4% of students selected "Not at all," indicating that many were reluctant to fully embrace this role, even though few students rejected the possibility outright.

It is evident from looking at the experimental group's responses that using the app during the workshop improved students' self-efficacy of their scientific abilities. It is crucial to take into account the responses from the control group, which engaged in the same activities using a conventional, paper-based method, in order to put these findings into context and obtain a more impartial viewpoint. The degree to which the app influenced students' perceived scientific confidence and engagement will be ascertained with the aid of this comparison.

Reliability Analysis and Descriptive Statistics of CSSES – Control Group

We start by applying reliability in the scale to observe consistency, using the same process as the experimental group. Cronbach's alpha, which was used to evaluate the internal consistency of the control group's responses, produced a coefficient of 0.815. This suggests that the items used to gauge students' perceived scientific self-efficacy form a coherent scale and show a high degree of reliability. The robustness of the instrument is particularly supported by the consistency across items like "Locate Macroinvertebrates" and "Count

Macroinvertebrates," both of which displayed comparatively high mean scores and strong correlations with the overall scale. The scale's suitability for deciphering trends in students' self-reported abilities is confirmed by the reliability analysis, which also offers a solid basis for comparison with the experimental group.

Additional information about students' self-perceived abilities in citizen science tasks can be found in the descriptive statistics for the control group. The item "help scientists with data collection" had the highest mean score (M = 3.87, SD = 1.08), indicating that participants felt a comparatively strong sense of contribution. "find Differences in macroinvertebrates" (M = 3.56) and "record macroinvertebrates" (M = 3.63) came in close succession. Items like "describe different macroinvertebrates" (M = 3.21, SD = 1.15) and "distinguish macroinvertebrates" (M = 3.32), on the other hand, had somewhat lower mean scores, which might indicate areas in which students felt less confident. The majority of students gave themselves a positive overall rating, as evidenced by the consistently high median scores of 4.

Table 26: Control group responses on citizen science task self-efficacy

Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Locate Macroinvertebrates	3.50	0.12	1.01	1	3	4	4	5
Count macroinvertebrates	3.43	0.12	1.09	1	2.5	4	4	5
Describe different macroinvertebrates	3.21	0.13	1.15	1	2	3	4	5
Find differences among macroinvertebrates	3.56	0.13	1.15	1	3	4	4	5
Distinguish macroinvertebrates from other animals	3.32	0.14	1.19	1	2	3	4	5
Record macroinvertebrates	3.63	0.13	1.13	1	3	4	5	5
Help Scientists with data collection	3.87	0.12	1.08	1	3	4	5	5

Following the same methods as the experimental group, Figure 21 shows pie charts to illustrate the response distribution for each skill-related item in order to provide a better understanding of these self-assessments. The percentage of students who expressed uncertainty or lower self-efficacy ("Not sure", "A little", or "Not at all") versus those who felt confident ("Well" or "Very well") is depicted in these visual aids. These charts and a breakdown of students' perceptions of their ability to find, count, describe, and record macroinvertebrates, as

well as their confidence to assist scientists with data collection, are presented in the section that follows.

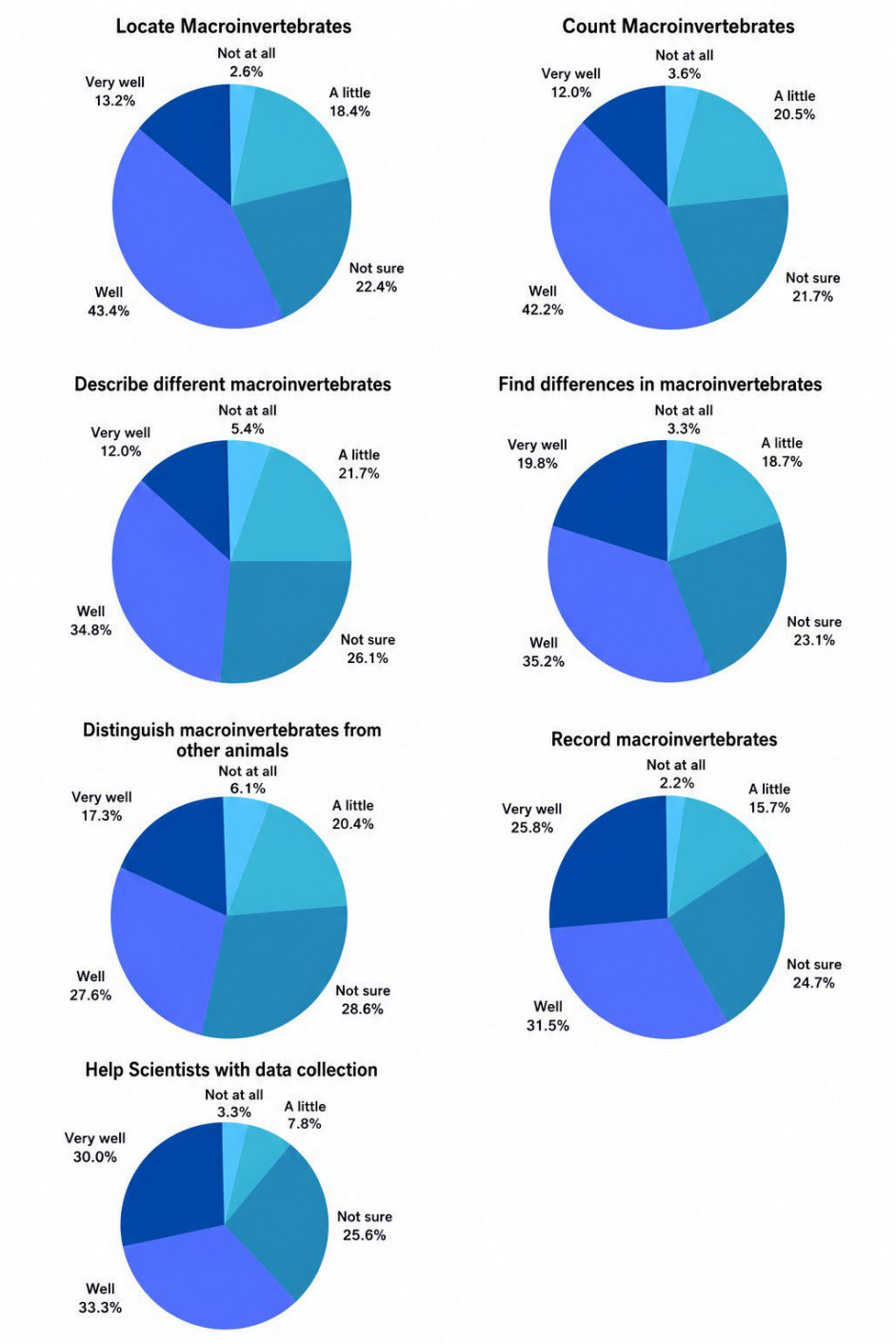


Figure 21: Distribution of students' self-perceived ability to contribute to citizen science tasks in the control group

In the category "locate macroinvertebrates," most students were confident in their abilities: 43.4% said they could do it "Well," and 13.2% said they could do it "Very well." However, 22.4% said they were "Not sure," and 2.6% said they couldn't do it "At all." This suggests a generally positive perception, though some uncertainty remained. When asked if they could "count macroinvertebrates," 42.2% said they could do this "Well," indicating relatively high confidence. However, 20.5% chose "A little," and 21.7% chose "Not sure," which may indicate difficulties in identifying or tracking specific organisms.

In the task "describe different macroinvertebrates," students felt less confident compared to the previous tasks. Although 34.8% said "Well," a sizable percentage said, "Not sure" (26.1%) or "A little" (21.7%), and 5.4% said "Not at all." This implies that additional direction or visual aids might have been needed when describing taxonomic features. A total of 55% of students evaluated their performance on the task "Find differences in macroinvertebrates" as either "Well" or "Very well," suggesting a reasonably high level of comprehension in this domain. However, in this comparison-based task, roughly 22% of the students felt less confident, and nearly a quarter (23.1%) were unsure. There was a little more variation in the confidence levels for the task "distinguish macroinvertebrates from other animals." While 27.6% of students chose "Well," only 17.3% selected "Very well," and nearly 49% selected "Not sure," "A little," or "Not at all." This might be a reflection of how taxonomic group distinctions are more difficult.

Responses for the "record macroinvertebrates" category were largely favourable, with 25.8% of students evaluating their performance as "Very well" and 31.5% as "Well." However, 15.7% said only "A little," and 24.7% said "Not sure," which may be the result of inexperience with data sheets or a lack of knowledge about recording procedures. Finally, when students were asked to rate their ability to "help scientists with data collection", this item showed one of the highest positive self-ratings: 30% of students selected "Very well," and 33.3% said "Well." This suggests that many students could visualise their role as contributors to a scientific project. Nonetheless, 25.6% were "Not sure," highlighting some ambiguity about what "helping scientists" might actually involve.

Building on the descriptive analysis and visual interpretation of students' perceived ability to contribute to scientific practices, it was necessary to explore whether any statistically significant differences existed between the experimental and control groups. Given the ordinal nature of the response scale and evidence of non-normal distribution in the data, a non-

parametric approach was deemed most appropriate. Therefore, the Mann–Whitney U test was selected to compare the two groups across each citizen science task, providing a more robust analysis of potential differences in self-efficacy without the assumption of normality.

Comparison of Experimental and Control Groups Across Self-Efficacy Measures

To summarise the comparative findings between the experimental and control groups, a Mann–Whitney U test was conducted for each citizen science task because responses were captured on an ordinal Likert scale and the distribution of scores did not meet the assumptions required for parametric tests. This non-parametric test compares the two groups' score distributions (using rank-based comparisons) without assuming normality. Table 27 presents the median scores for each group, the corresponding test statistics and p-values, and indicates whether each difference was statistically significant. This overview highlights where the most notable differences between groups were observed and provides a basis for the interpretations that follow.

Table 27: Groups Across Self-Efficacy Measures

Task	**Median (Exp)**	**Media (Con)**	**W-Value**	**p-Value**	**Significant**
Locate macroinvertebrates	4	4	4888.50	.008	Yes
Count macroinvertebrates	4	4	5302.50	.185	No
Describe different macroinvertebrates	3	4	4902.50	.005	Yes
Find differences in macroinvertebrates	4	4	5158.50	.056	No
Distinguish from other animals	3	4	4976.00	.103	No
Record macroinvertebrates	4	4	5375.50	.687	No
Help scientists with data collection	4	4	5671.00	.400	No

To determine whether there was a statistically significant difference in students' perceived ability to locate macroinvertebrates between the experimental group and the control group, a Mann-Whitney U test was conducted. The results identified a statistically significant difference between the two groups, W = 4888.50, p = .008 (adjusted for ties), which suggests that there is a difference in the distribution of perceived ability scores between the two teaching approaches, although both groups shared the same median (Mdn = 4). This suggests that students in the experimental group tended to indicate marginally different confidence levels than their control-group peers, despite the fact that their central tendencies look about the same.

In the task of describing different macroinvertebrates, the experimental group scored a lower median (Mdn = 3) than the control group (Mdn = 4). There was a significant difference between groups (U = 4902.50, p =.005), showing that students using the traditional paper-based method were more confident that they could describe. This may reflect the benefits of working with printed identification guides directly, which may offer more structure or pictorial detail. In identifying differences in macroinvertebrates, both the experimental group and the control group showed the same median score (Mdn = 4), indicating similar perceived competence levels. The p-value for this comparison was 0.056 (with ties adjusted), just higher than the conventional significance level of 0.05. As it stood, there was no apparent difference between the groups statistically. This means that both

instructional methods, digital and traditional, had an equally positive impact on students' confidence in identifying distinguishing traits among

macroinvertebrates.

In distinguishing macroinvertebrates from other animals, the experimental group had a median score of 3, while the control group had a very slightly higher median score of 4. Although

there was this difference, the result was nevertheless not statistically significant (p =.103, adjusted). Even though the baseline group was more confident in this area to an extent, lack of statistical significance means that the two pedagogies helped the students in relatively similar ways. For the task of recording macroinvertebrates, both the experimental and control groups reported the same median score (Mdn = 4), indicating a comparable level of confidence. The result was not statistically significant (p = .687, adjusted for ties), suggesting that students felt equally capable of recording data, regardless of whether they used the AquaInverts app or traditional paper-based materials.

To help scientists obtain data, the experimental and control groups both had a median score of 4, thus capturing equivalent levels of self-evaluation competence. The comparison was not significant (p = .400, adjusted for ties) and went on to show that there was no actual difference between groups. Thus, the use of the AquaInverts app did not appear to influence students' confidence in helping scientific data collection against the traditional paper-based practice.

Chapter Summary

To sum up, the findings for RQ1 indicate that both approaches generated generally high engagement and positive learning perceptions in the workshop context. Across the matched items, the paper-based approach tended to score higher on enjoyment, excitement, perceived interest, and intention to reuse/share, suggesting stronger affective engagement and willingness to repeat the activity. In contrast, the AquaInverts (app-based) approach showed slightly stronger scores on readability and perceived ease of identification, while perceived learning ("I learned something new") remained high in both groups. Overall, the engagement results suggest that both approaches supported pupils' participation in the activity, with differences emerging mainly in the balance between affective enjoyment and practical usability.

The findings for RQ2 show that most pupils in both groups reported moderate to high confidence in their ability to contribute to citizen science tasks. Comparative testing identified two

statistically significant differences across the seven assessed tasks: pupils in the experimental (app-based) group reported greater confidence in their ability to locate macroinvertebrates, while pupils in the control (paper-based) group reported higher confidence in describing different macroinvertebrates. For the remaining tasks, no statistically significant differences were observed and median scores were broadly consistent across groups. Overall, these results suggest that both approaches supported pupils' self-reported ability to contribute to science in a largely comparable way, with variation evident only for specific task areas.

To conclude, Chapter 4 compared pupils' responses across app-based and paper-based workshop approaches in relation to (1) engagement with the activity and (2) perceived ability to contribute reliable scientific information as citizen scientists. For engagement (RQ1), both approaches produced positive outcomes, though the paper-based approach was associated with stronger enjoyment- and reuse-related responses, while the app-based approach showed small advantages in usability-related aspects such as readability and perceived ease of identification. For self-efficacy (RQ2), pupils in both groups reported moderate to high confidence overall, with only task-specific differences emerging between groups. Together, these findings provide a structured basis for the interpretation and discussion developed in the following chapter.

Chapter 5

Discussion

This chapter discusses the study findings in relation to the aims and research questions set out in Chapter 1. The study examined how EE and Science Outreach workshop on freshwater conservation supported primary school pupils' learning and engagement, and whether outcomes differed when the same activity was delivered through two approaches: an app-based approach using the AquaInverts App and a traditional paper-based identification approach. In line with the main research question*: How can EE activities enhance children's awareness of water conservation, and what role does digital technology play in this process?* The discussion considers what the findings suggest about the contribution of digital tools within a workshop-based EE context, while recognising that the broader purpose was not simply to compare technologies but to support meaningful engagement with local freshwater environments and participation in citizen science.

Central to this study was the goal of fostering scientific self-efficacy and a sense of belonging in science by making scientific inquiry more approachable, enjoyable, and grounded in everyday experience. To interpret the findings, two validated frameworks were used across the study instruments. Engagement-related outcomes were examined through constructs adapted from the Technology Acceptance Model (TAM) (Camilleri & Camilleri, 2019), capturing pupils' perceptions of usefulness, ease of use, and enjoyment in relation to the workshop approach. Pupils' perceived ability to contribute to science was examined using an adapted version of the Citizen Science Self-Efficacy Scale (CSSES) developed by Hiller and Kitsantas (2016), reflecting confidence in completing citizen science tasks relevant to macroinvertebrate identification and documentation.

The sections that follow discuss the findings for engagement (RQ1) and self-efficacy (RQ2) and consider their implications for digital EE and CS practice in primary school contexts. However, emerging perspectives in EE, such as those advanced by Heggen et al. (2019), framed children not as passive recipients of knowledge but as eco-citizens, individuals capable of meaningful participation in environmental stewardship from an early age. This view calls for educational approaches grounded in children's lived experiences, encouraging action within their own communities. In this light, the pedagogical design of this study, combining CS with local, place-based ecological exploration, can be understood as an attempt to reconnect children with their immediate environments while fostering a sense of

relevance, agency, and ecological identity.

The local pond, in this context, becomes? more than a site of learning; it becomes a space of encounter between children and the more-than-human world. As Louv (2005) eloquently states, "passion is lifted from the earth itself by the muddy hands of the young; it travels along grass-stained sleeves to the heart" (p. 159). By enabling students to explore local ecosystems hands-on, even though it was within classroom, with tools that invite curiosity and agency, this project also responds to Louv's warning that "care for nature increasingly becomes an intellectual concept, severed from the joyful (youthful) experience of the outdoors" (p. 147).

In this sense, the EE and CS workshop was intentionally designed to be more than a brief interaction with a digital tool. It represents a broader pedagogical response to what Louv poignantly calls "an endangered indicator species: the child in nature" (p. 159). This chapter that follows interprets the findings through this lens, linking them to the theoretical frameworks that guided the study and to contemporary concerns in environmental and science education. It also considers practical implications for school integration, reflects on the limitations of the study, and offers recommendations for future research and educational practice.

Interpretation of Key Findings RQ1: Engagement with the Mobile App vs. Traditional Method

This question examined how primary school children engaged with two instructional approaches for environmental learning: an app-based approach using AquaInverts and a traditional paper-based identification key. Drawing on the descriptive statistics and group comparisons presented in Chapter 4, the analysis considered how pupils responded to each approach across key engagement-related dimensions, including enjoyment, excitement, perceived usefulness, usability, and intentions to reuse and share.

Enjoyment and Excitement: Traditional Activity Outperformed the App

Although the *AquaInverts* app was designed to be interactive and engaging, children in the control group who used the paper-based identification key reported significantly higher levels of enjoyment and excitement overall. The mean enjoyment score for the paper-based group was 4.44, compared with 4.12 for the app-based group. Similarly, measures of excitement during the activity reflected this trend, with the paper group scoring an average of 4.50 compared to 3.91 for those using the app. This finding aligns with critiques in the educational technology literature that question the assumption that interactivity alone

inherently enhances engagement and learning outcomes (Ke & Hoadley, 2009; Mayer, 2005). In particular, these authors argue that the effectiveness of digital interactivity depends on how tools are designed and implemented in context.

This challenges long-standing assumptions within the educational technology literature, where interactive digital tools, particularly mobile applications, have often been assumed to inherently enhance engagement and deepen learning. Ke and Hoadley (2009), for example, reviewed 42 empirical studies and questioned the universal efficacy of digital interactivity. Similarly, Mayer's (2005) influential work on multimedia learning identified key interactive features, such as learner control, visual feedback, and navigational flexibility, as potentially beneficial for engagement and cognitive processing. However, he also warned that, if poorly implemented, these features could contribute to cognitive overload or distraction.

It is important to contextualise Mayer's research within its historical moment: his conclusions were drawn nearly two decades ago, at a time when digital learning tools were far less sophisticated and less responsive to the developmental needs of younger learners. Since then, educational technologies, particularly those aimed at primary education, have evolved significantly in terms of usability, adaptability, and pedagogical nuance. Yet, this study's findings suggest that such advancements do not automatically guarantee higher emotional involvement or learner enjoyment, underscoring the continued relevance of careful pedagogical design in both digital and non-digital formats.

Yet despite these developments, recent research suggests that many educational apps continue to fall short of developmental and pedagogical standards. Meyer et al. (2021), using the Four Pillars of Learning framework, found that most of the top-downloaded children's educational apps scored poorly across all four domains: active learning, engagement, meaningfulness, and social interaction. Their analysis revealed that while many apps feature interactive components, these are often superficial and do not effectively support deeper cognitive or emotional engagement, particularly in free apps where distracting enhancements and advertisements are prevalent. The findings of the present study reinforce this critical perspective. While the AquaInverts app was designed with pedagogical intent and included interactive features, it did not elicit the same level of emotional engagement as the traditional paper-based activity. It is worth noting that both groups had identical activities with only a difference in the identification method.

This outcome suggests that the group using paper may have experienced a more tactile and socially collaborative learning experience. This interpretation is supported by the

engagement results reported in Chapter 4, where the paper-based group reported higher enjoyment and excitement and stronger intentions to reuse and share the activity than the app-based group. In

primary education, particularly within environmental learning contexts, these affective and social dimensions can be important for meaningful engagement with both content and setting. Thus, while interactive technologies have evolved, their pedagogical effectiveness remains contingent upon thoughtful, developmentally appropriate design. Kirkwood and Price (2014) highlighted over a decade ago the assumption that when educational technologies are integrated into education, this will invariably translate into increased engagement and enhancements to students' learning experiences.

These findings also resonate with the theoretical perspective of embodied cognition, which posits that learning is deeply rooted in bodily interaction with the environment (Wilson, 2002). Physical engagement with materials and collaborative activity within real-world contexts can generate emotional and sensory experiences that are difficult to replicate through screen-based tools, regardless of how well they are designed (Fleer, 2010). This is particularly salient in outdoor and environmental education, where the richness of sensory inputs such as ? touch, smell, movement and sound can deepen learners' emotional engagement and sense of place. As Louv (2005) evocatively remarked, "passion is lifted from the earth itself by the muddy hands of the young" (p. 159), emphasising that affective engagement with the natural world is often forged through unmediated, tactile experiences.

In the current study, the traditional paper-based activity appeared to provide more opportunities for shared discovery, hands-on exploration, and contextually grounded interaction, dimensions that may be restricted or abstracted in screen-centred tasks. This is particularly salient in outdoor and environmental education, where the richness of sensory inputs such as touch, smell, movement, and sound can deepen learners' emotional engagement and sense of place. As Louv (2005) evocatively remarked, "passion is lifted from the earth itself by the muddy hands of the young" (p. 159), emphasising that affective engagement with the natural world is often forged through unmediated, tactile experiences.

Moreover, this emotional connection is not merely a by-product of environmental education but a central goal. Three decades ago, Sobel (1995) argued that fostering a sense of wonder and empathy for the natural world is more foundational in childhood than the transmission of ecological facts. He contends that "what's important is that children have an opportunity to bond with the natural world, to learn to love it and feel comfortable in it, before

being asked to heal its wounds" (Sobel, 1995, p. 5).

The higher enjoyment and excitement observed among children in the traditional group using the paper may therefore reflect this deeper affective engagement, which is critical in cultivating lasting ecological awareness. In summary, while the AquaInverts app was designed
with educational intent and featured interactive elements, it did not elicit the same level of emotional engagement as the traditional method. These findings support a balanced, critical approach to educational technology, one in which digital tools are thoughtfully embedded within multisensory, collaborative, and contextually grounded learning experiences. Especially in environmental education, where emotional connection is foundational to ecological literacy, such considerations are not peripheral but essential.

Perceived Usefulness (PU): I learned something Knew

Despite lower ratings in enjoyment and emotional engagement, the app-based group reported higher perceived learning overall, with a mean score of 4.72 compared to 4.67 for the control group. Although this difference is small, it suggests that the app was seen as equally, if not slightly more, effective in supporting learning outcomes than the traditional method. This finding reinforces the notion that interactivity, when well-designed and content-specific, can support cognitive engagement, even if it does not necessarily elicit stronger emotional responses.

Again, Mayer's (2005) cognitive theory of multimedia learning offers a useful framework for interpreting these findings. The theory posits that interactive features, when appropriately aligned with learning objectives, can enhance learners' ability to select, organise, and integrate new information. Notably, children in the experimental group reported the highest levels of perceived learning. This suggests that the app was effective in fulfilling its instructional function, reinforcing the notion that interactivity, when well-structured, can facilitate cognitive processing and content retention.

In a similar vein, Papadakis et. al (2018) found that educational apps can reinforce science-related concepts effectively when they are developmentally appropriate and pedagogically scaffolded. In the present case, while the app may have lacked the affective and collaborative richness associated with the traditional paper- based activity, it appears to have succeeded in supporting conceptual understanding. This highlights the importance of distinguishing between cognitive achievement and emotional engagement when evaluating educational tools, particularly in environmental education, where both dimensions are crucial

but not always equally addressed by digital media. The high perceived learning score attributed to the app demonstrates that effective content delivery is possible through digital means, even as the affective dimensions of learning remain more powerfully activated through tactile, place-based, and social experiences.

Perceived Usefulness (PU): The app-based group is slightly higher

Although the app-based group reported slightly higher levels of perceived learning, they rated the usefulness of the information less favourably than the control group (M = 4.14 vs. 4.45). This difference suggests a possible disconnect between cognitive engagement and the perceived relevance of digital content. While the children may have interacted effectively with the app, they may not have found its information as meaningful or applicable as that presented in the traditional method. One contributing factor may lie in the nature of the app's content delivery: despite being interactive, it may have lacked the contextual richness, narrative depth, or authenticity that characterise more situated learning experiences, particularly important in environmental education, where real-world connections are pedagogically vital.

Research by Meyer et al. (2021) has shown that many educational apps prioritise engagement mechanisms, such as animations or gamified feedback, often at the expense of deeper conceptual integration. Similarly, Papadakis et al. (2018), through their Developmentally Appropriate Mobile Learning (DAML) model, emphasise that meaningful mobile learning requires more than technical interactivity; it must be attuned to learners' developmental needs and situate information within familiar or experiential contexts. Their findings indicate that when digital tasks are not embedded in authentic, real-world scenarios, children may struggle to perceive the content as practically useful.

This concern is echoed by Bano et al. (2018), who found in their systematic review of mobile learning in science and mathematics education that perceived usefulness is often limited when learning experiences lack contextual relevance and pedagogical coherence. While mobile tools can enhance engagement, their educational impact depends on thoughtful instructional design that connects digital content to learners' immediate environments and tasks.

In contrast, the traditional paper-based method used in this study may have allowed learners to engage more with the scientific task, observing, discussing, and identifying macroinvertebrates in a contextually grounded, hands-on setting. This form of embodied interaction likely made the information feel more meaningful and relevant. These findings underscore the importance of designing digital tools that are not only cognitively stimulating

but also pedagogically coherent, contextually grounded, and emotionally resonant. In educational domains such as environmental science, where emotional and sensory engagement with place is critical, perceived usefulness depends not only on the quality of information, but also on the mode and context in which it is delivered.

Perceived Ease of Use (PEoU): Usability and Readability A Small Edge for the App

While the paper-based method outperformed the app in emotional engagement and perceived usefulness, the findings on perceived ease of use (PEoU) present a more nuanced perspective. Participants in the experimental group rated readability slightly higher than those in the control group (M = 4.14 vs. 4.00), suggesting that the app's digital interface may have facilitated a clearer visual presentation of textual content. This aligns with Papadakis et al. (2018), who argue that well-designed mobile apps can enhance access to information through optimised layouts and intuitive interface features tailored to young users.

Moreover, Chen (2022) supports this by emphasising that interactivity and feedback, key principles in their interactive emotional design framework, can enhance the clarity and usability of children's apps when aligned with developmental needs. As Chen notes, "the goal of emotional design is to generate positive emotions in users when interacting with the product, based on user research" (Chen, 2022, p. 87), reinforcing the importance of emotionally resonant interfaces in digital learning tools.

However, the app group also rated task difficulty higher (M = 3.84 vs. 3.41), indicating that despite the interface's visual clarity, the cognitive or procedural demands of identifying macroinvertebrates through the app were perceived as more challenging. This may reflect navigation complexity, decision-tree structures, or the visual density of dynamic content. As noted by Bano et al. (2018), while mobile learning environments often support readability and engagement, their usability must also manage cognitive load, procedural clarity, and task flow, factors that are often overlooked in app development when visual engagement is prioritised over functional design.

Similarly, the systematic review by Weichbroth (2020) underscores that usability in mobile applications depends not only on aesthetic appeal or interface clarity, but on how effectively the system minimises user effort, maintains task consistency, and reduces unnecessary cognitive burden. He identifies learnability and efficiency as especially important for novice users, such as primary school children, who benefit from predictable navigation paths, feedback cues, and task continuity.

In this study, the app's layered structure and required user inputs may have introduced friction points in the learning flow, subtly increasing the perceived difficulty despite overall gains in readability. Furthermore, while both groups reported that identifying macroinvertebrates was "easy," the digital condition may have imposed hidden layers of complexity that are not immediately visible through surface-level usability metrics. For instance, screen size limitations, swipe-based navigation, and the absence of tactile manipulation may contribute to small but cumulative increases in mental effort. As Weichbroth (2020) cautions, effective usability must be evaluated not solely through user preference or satisfaction but also via task-based performance indicators that reveal the actual cognitive demands placed on the learner.

These findings reinforce the importance of a holistic approach to usability in educational app design, one that integrates developmental psychology, user interface research, and pedagogical theory. Particularly in the context of environmental science education, where tasks often require multi-step reasoning and field-based observation, digital tools must not only support clear content delivery but also facilitate smooth and intuitive task execution. In sum, while the app demonstrated a slight advantage in readability, its higher task difficulty scores suggest that interface design alone does not guarantee ease of use. Rather, a well-balanced interaction between design simplicity, cognitive scaffolding, and contextual relevance is critical for maximising learning outcomes.

Intention to Reuse and Share: Traditional Method Favoured

Among all measured dimensions in RQ1, the most pronounced differences between the two groups emerged in students' intention to redo the activity and their willingness to share the experience with others. Students in the traditional, paper-based group reported significantly higher scores on both measures (Reuse: M = 4.65 vs. 3.88; Sharing: M = 4.13 vs. 3.42). This suggests that the tactile, collaborative, and socially grounded nature of the traditional activity fostered a deeper sense of personal investment and affective resonance than the app-based alternative.

This distinction reveals more than a preference for one method over another, it reflects differing levels of emotional connection and intrinsic motivation, both of which are critical in shaping not only what children learn, but how they value and communicate that learning. While the app facilitated individual exploration, it may have lacked the shared immediacy and

embodied engagement that catalyse enthusiasm and ownership. According to Self-Determination Theory (Ryan & Deci, 2000), intrinsic motivation arises when learners experience autonomy, competence, and especially relatedness, a sense of belonging and connection. The context of the traditional activity likely met these psychological needs more fully, encouraging not only re-engagement but also a desire to share the experience with others.

This is particularly salient in the field of environmental education, where affective engagement is not ancillary, but foundational. As educators such as Sobel (1996) have long argued, meaningful ecological literacy depends not just on knowledge acquisition, but on emotional connection to place and personal meaning-making through experience. When learners feel moved by an activity, when they are allowed to touch, observe, and discuss their environment in real time, they are more likely to internalise its relevance and advocate for it. In this study, the group more inclined to share their learning was also the group more physically and socially immersed in the activity, reinforcing the idea that relational and sensory engagement amplifies environmental connection.

Pischetola's (2021) critique of digital determinism, the assumption that introducing technology will, by itself, produce educational improvement, further supports this view by calling attention to the socio-material dimensions of learning often flattened in digital environments. Her work reminds us that technologies are not neutral conduits of information, but are embedded in human, spatial, and emotional relations. The traditional activity's success in promoting reuse and sharing may thus stem from its ability to position children not just as users, but as active participants in a shared ecological and pedagogical experience.

From a design perspective, these results imply that educational technologies must prioritise not only individual usability, but collective engagement and emotional resonance. Features that promote collaboration, dialogue, and co-exploration, such as shared discovery tools, narrative scaffolding, or discussion prompts, could help replicate some of the social and affective benefits traditionally afforded by physical, field-based learning. Without such considerations, even pedagogically sound apps may fall short of fostering the sense of connection that drives learners to return to and share what they have learned.

In conclusion, the traditional paper-based method in this study did more than deliver information, it enabled children to feel a part of the learning environment, cultivating emotional engagement, social bonding, and a willingness to carry the experience beyond the confines of the task. In environmental education, where connection often precedes conservation, these

findings underscore the vital role of pedagogies that are not only cognitively effective but emotionally compelling and socially embedded.

At this point, it is possible to draw together the answer to RQ1. Overall, the findings suggest that both instructional approaches supported high levels of pupil engagement and perceived learning, but they did so in slightly different ways. The paper-based activity was associated with stronger affective engagement (enjoyment and excitement) and higher intentions to reuse and share the activity, while the app-based approach showed small advantages in usability-related aspects such as readability and perceived ease of identification. Taken together, these results indicate that digital novelty alone does not guarantee heightened engagement; rather, engagement appears to depend on how the activity supports social interaction, meaning-making, and developmentally appropriate participation in the task.

Having examined the comparative outcomes of the app-based and paper-based approaches in terms of engagement, the discussion now turns to RQ2, which considers pupils' perceived ability to contribute to science through citizen science tasks.

RQ2: Scientific Self-Efficacy and the Citizen Science Experience

The second research question explored the extent to which participation in the workshop influenced pupils' self-efficacy in undertaking authentic scientific tasks. Anchored in the theoretical framework of citizen science and employing an adapted version of the CSSES (Hiller and Kitsantas, 2016), this part of the study focused on learners' perceived abilities to observe, identify, record, and contribute to scientific data collection. Self-efficacy, as defined by Bandura (1997), plays a pivotal role in shaping motivation and sustained engagement, particularly within inquiry-driven educational settings.

In the context of environmental education, where experiential learning, hands-on exploration, and real-world relevance are paramount, supporting students' confidence in their scientific competence serves not only to enhance knowledge acquisition but also to lay the groundwork for longer-term environmental stewardship. By comparing the responses of students in both the experimental and control groups, this section examines how digital and traditional modes of engagement differentially influenced learners' confidence in performing scientific roles.

These findings are considered in relation to recent empirical research in the fields of citizen science, digital education, and environmental pedagogy, in order to evaluate their

broader educational implications and the potential of each modality to support transformative learning experiences.

Task-Specific Discussion of Scientific Self-Efficacy

Locating Macroinvertebrates: Enhancing Observational Self-Efficacy through Digital Interaction

The ability to locate macroinvertebrates is a fundamental aspect of CS, involving direct, hands-on engagement with the natural world through careful observation. Both the experimental and control groups reported a median confidence score of 4 ("Well"), suggesting that students in general felt capable in this task. However, a closer look at the average scores reveals a meaningful distinction: the experimental group achieved a mean of 3.90 (SD = 0.92), while the control group averaged 3.50 (SD = 1.01). Although the medians were identical, the higher mean and narrower range of responses in the experimental group point to a more consistent level of confidence among those students. This interpretation is supported by a statistically significant difference between groups ($p = .008$).

These results suggest that the AquaInverts app may have provided a more stable and positive experience for students when identifying macroinvertebrates. The app's real-time visual aids, structured prompts, and immediate feedback likely contributed to students feeling more capable in an unfamiliar field context. This aligns with the findings of Hiller and Kitsantas (2016), who, through the development of the CSSES, demonstrated that confidence in observational tasks increases when learners are supported with appropriate scaffolding.

As highlighted in the previous literature review, CS strengthens not only subject knowledge but also confidence and motivation, particularly when students are able to engage directly with their surroundings (Bonney et al., 2009; Makuch and Aczel, 2018). The AquaInverts app appears to have played a key role in facilitating this engagement, helping students to interpret the macroinvertebrates activity more easily by simplifying the process of locating them. This observation is consistent with the work of Tillotson-Chavez and Weber (2024), who reported that mobile applications such as iNaturalist enhanced learners' observational precision and motivation across educational levels.

Furthermore, this outcome reflects the perspective of Heggen et al. (2019), who encourage recognition of children as capable eco-citizens, able to contribute meaningfully to

environmental knowledge when given the right tools. The higher mean score in the experimental group suggests that the digital interface functioned not just as a technological aid but as a learning tool that empowered students to participate more confidently in real-world scientific practice. Children possess an innate curiosity and a strong desire to explore and learn, which can enhance their engagement with CS, as demonstrated by research (Jenkins, 2011; Makuch and Aczel, 2018).

Lastly, the findings support the idea, also discussed in literature review chapter, that technology can reduce cognitive load, particularly in tasks requiring pattern recognition and environmental scanning (Mayer, 2005; Zydney & Warner, 2016; Bano et al., 2018). By offering consistent guidance and feedback, the AquaInverts app may have alleviated some of the uncertainty typically associated with unstructured observation, thereby enabling more students to feel successful in the task.

In conclusion, while students in both groups reported generally high levels of confidence, those who used the AquaInverts app demonstrated significantly more consistent self-assurance. This suggests the app not only supported individual learning but also helped foster a broader sense of confidence across the cohort. Such tools show clear potential for promoting meaningful interaction with nature, an essential aim of CS within EE.

Counting Macroinvertebrates: Task Familiarity and Consistency Across Modalities

The task of counting macroinvertebrates yielded comparable self-efficacy outcomes across both the experimental and control groups. Both reported a median score of 4 (“Well”), indicating a high overall sense of ability in this core quantitative skill. However, the mean scores suggest a subtle difference: the experimental group achieved a mean of 3.69 (SD = 0.97), while the control group scored slightly lower at 3.43 (SD = 1.09). Although this difference was not statistically significant ($p = .185$), it may suggest that students using the AquaInverts app experienced a marginal confidence boost in completing the task.

This modest difference could be attributed to the app’s interactive design, which may have made the counting process more intuitive and less cognitively demanding. As noted by Bonney et al. (2009) and reiterated by Ballard et al. (2017), digital tools within CS settings often increase engagement and accuracy by clarifying procedures and sustaining motivation. While both groups reported strong overall confidence, the slightly higher mean in the experimental group may indicate that fewer students experienced hesitation or uncertainty. This supports research suggesting that visual and tactile aids might help young learners

organise and carry out scientific observations with greater assurance.

Bandura's (1997) theory of self-efficacy emphasises the importance of mastery in task-specific contexts. Counting macroinvertebrates demands precision, familiarity with numerical processes, and confidence in one's observational accuracy. Students using the AquaInverts app may have benefited from prompts or visual guidance that structured the task in a more manageable format, thereby increasing their self-perceived reliability. This interpretation aligns with Hiller and Kitsantas (2016), who found that well-scaffolded CS experiences tend to reinforce confidence, particularly when learners receive immediate, structured feedback.

Nonetheless, the similarity in means and medians across the two groups also suggests that counting may be less sensitive to differences in instructional modality compared to more interpretative tasks, such as classification or data interpretation. Counting is procedural and may be effectively supported by traditional methods, such as tally sheets or checklists, provided the instructional delivery is clear and well structured. This aligns with critiques in the educational technology literature that question the assumption that technological mediation is inherently beneficial and emphasise that learning outcomes depend on pedagogical design and implementation, regardless of format (Ke & Hoadley, 2009; Kirkwood & Price, 2014; Mayer, 2005).

Broadly speaking, this finding supports Heggen et al. (2019), who argue for acknowledging children as capable eco-citizens, fully able to engage in scientific inquiry when suitably supported. Whether using paper-based materials or digital applications, students in both groups demonstrated the capacity to conduct and reflect on quantitative biological tasks with confidence, an essential building block in developing scientific agency. CS provides an avenue for children and young people to participate in research and inquiry from their distinct perspectives, potentially leading to alternative solutions and novel understandings of various issues, as observed by Wells and Lekies (2006).

Finally, while the AquaInverts app may provide some additional support in scaffolding counting practices, both instructional approaches appear effective in fostering student confidence for this task. This reinforces a key point: that CS is adaptable by nature, and that meaningful participation can be cultivated through both digital and traditional methods, provided the tools are developmentally appropriate and pedagogically grounded. As Makuch and Aczel (2018) point out, the adaptability and promotion of diversity can create opportunities for children participation in CS projects.

Describing Different Macroinvertebrates: The Role of Visual Structure in Supporting Scientific Language

This task produced one of the clearest distinctions between the two instructional groups. Although students in both the experimental and control groups engaged in observation-based activities, the control group reported a higher median self-efficacy score (Median = 4) compared to the experimental group (Median = 3). The difference in mean scores, 3.21 (SD = 1.15) for the control group and 3.75 (SD = 0.88) for the experimental group, was statistically significant ($p = .005$). This suggests that students using traditional paper-based materials felt more confident in their ability to describe macroinvertebrates than those using the AquaInverts app.

This outcome is particularly noteworthy, as it stands in contrast to previous tasks where the digital tool appeared to offer clear advantages. While interactive apps may enhance observational confidence and support identification, the process of description requires students to express observed features using precise scientific language, a task that may be better supported through static, structured resources. Paper-based identification keys often include clearly labelled diagrams, consistent terminology, and repeated opportunities to encounter descriptive vocabulary. These features can help reinforce students' confidence in their ability to articulate scientific observations.

As highlighted in previous studies, while CS initiatives have been shown to boost engagement and scientific confidence (Bonney et al., 2009; Ballard et al., 2017), their effectiveness can vary depending on the cognitive demands of specific tasks. Scientific description, in particular, involves not only observing but also interpreting and verbalising findings. Hiller and Kitsantas (2016) note that such tasks require more than visual input, they also demand a strong conceptual foundation and support for linguistic expression, which are often more effectively delivered through structured, text-based resources.

These findings also resonate with the work of Heggen et al. (2019), who stress that developing children's identities as eco-citizens involves equipping them with the language and conceptual frameworks needed to articulate ecological relationships. If digital tools lack embedded support for scientific language development, they may fall short in helping students gain confidence in this area, despite enhancing visual engagement. In this light, the higher confidence levels observed in the control group may reflect the relative advantages of familiar, linguistically rich educational tools. Traditional field guides or worksheets may have provided

students with a clearer structure for framing their descriptions.

In contrast, while the app may have engaged students visually, it might have offered fewer cues or models for formulating descriptive statements. This points to a potential area for improvement in digital CS tools, specifically, the need to integrate linguistic scaffolds, embedded glossaries, or interactive language-building features to support the development of communication skills. In conclusion, the significant disparity in descriptive self-efficacy between groups highlights the importance of aligning instructional formats with the specific cognitive requirements of each task. While the AquaInverts app showed clear strengths in supporting identification and observational confidence, traditional materials proved more effective in facilitating scientific description. These results have implications for the future design of educational technologies in CS, particularly in fostering both ecological understanding and the ability to communicate that understanding clearly.

Identifying Differences Among Macroinvertebrates: Comparative Reasoning in Analog and Digital Contexts

The ability to distinguish differences among macroinvertebrates engages students in a comparative analytical process, requiring close attention to morphological detail. Both the experimental and control groups reported a median self-efficacy score of 4, indicating that most students felt confident in their ability to complete this task. However, the mean score for the experimental group was marginally higher at 3.94 (SD = 0.93), compared to the control group's mean of 3.56 (SD = 1.15). While this difference was not statistically significant ($p = .056$), it approaches the threshold for significance and suggests a noteworthy trend deserving further exploration.

These findings suggest that the AquaInverts app may have offered a modest benefit in supporting this skill, likely through its capacity to facilitate real-time comparisons and deliver visual prompts that aid analytical observation. As discussed in the literature review, interactive digital tools in CS contexts have been shown to strengthen observational accuracy and increase engagement, particularly when tasks involve pattern recognition or distinguishing fine features (Makuch & Aczel, 2018; Kelemen-Finan et al., 2018).

This outcome also aligns with research by Cutter-Mackenzie and Rousell (2019) and Heggen et al. (2019), who stress the importance of viewing children as capable eco-citizens. These studies argue that when children are provided with meaningful, embodied learning

experiences, such as those enabled through digital platforms, they are able to engage confidently with complex ecological tasks. The AquaInverts app, by scaffolding visual comparisons dynamically and engagingly, appears to have helped more pupils in the experimental group view themselves as capable of discerning subtle biological differences, an essential competency in science education.

Furthermore, this near-significant result resonates with broader themes from the literature review concerning pupils' natural capacity for inquiry and exploration (Jenkins, 2011; Wells and Lekies, 2006). When pupils are given tools that reinforce their sense of agency, whether digital or analogue, they are often able to perform at surprisingly advanced analytical levels. The AquaInverts app may have harnessed this potential by easing cognitive demands, providing opportunities for repeated practice, and reinforcing confidence through guided success. Nevertheless, wider research in CS education continues to highlight the value of clear and age-appropriate instructional support. Miczajka et al. (2015) underline the importance of presenting scientific tasks in an accessible language and structure, especially those involving comparison or distinction. This may account for the strong performance of some pupils in the control group, who, with the support of familiar paper-based materials and teacher scaffolding, were able to approach the task with confidence and accuracy.

From an educational standpoint, this finding reinforces the conclusion, reflected in studies by Varaden et al. (2021) and Castagneyrol et al. (2019), that task design plays a central role in shaping learning outcomes and self-perceived competence. Even in the absence of statistical significance, the higher average self-efficacy score among experimental group students points to a broader positive influence of the app in developing comparative reasoning, a fundamental component of biological education. Finally, although both groups demonstrated solid confidence in their ability to identify differences among macroinvertebrates, the slightly higher mean score in the experimental group suggests that the AquaInverts app contributed to a more consistently positive learning experience. This finding underscores the potential of well-designed digital tools to enhance analytical observational skills in younger learners, particularly when these tools are thoughtfully aligned with the pedagogical aims of school- based CS programmes.

Recording Macroinvertebrates: Data Literacy and the Equivalence of Instructional Formats

Recording macroinvertebrates, systematically documenting observations, is a

fundamental skill in CS, combining careful observation with basic data literacy. Both the experimental and control groups reported a median self-efficacy score of 4, suggesting a generally high level of confidence in completing this task. The experimental group achieved a slightly higher mean score (3.72, SD = 1.04) compared to the control group (3.63, SD = 1.13), although this difference was not statistically significant ($p = .687$), indicating broadly similar outcomes in perceived competence across the two instructional formats.

Despite the statistical equivalence, the marginally higher average in the experimental group may point to a minor advantage offered by the AquaInverts app in supporting procedural accuracy. Digital platforms often include structured input formats, dropdown menus, or built-in error checks, which can reduce uncertainty and guide learners through data entry. This echoes findings in the literature review, particularly from Ballard et al. (2017) and Makuch and Aczel (2018), who highlight the role of digital scaffolding in enhancing confidence for tasks requiring precision and consistency.

However, the strong median scores in both groups suggest that the task of recording data may be less sensitive to the mode of delivery than tasks such as description or classification. Here, the clarity and repetition of the task itself may have played a greater role in building student confidence. Whether using a paper-based template or a digital interface, students were likely able to transfer their observational data into a structured format with relative ease. This supports points raised in the literature review by Miczajka et al. (2015) and Castagneyrol et al. (2019), which emphasise the importance of age-appropriate task design in shaping learning outcomes, sometimes more so than the tools used to deliver the instruction.

It is also important to consider the impact of consistency in format. Traditional materials often provide a straightforward and familiar structure for recording data, which can be easier for younger learners to internalise and replicate. By contrast, while the AquaInverts app may offer interactive advantages, any lack of intuitiveness in its interface could present a barrier for some students, potentially affecting confidence levels. This consideration is consistent with Varaden et al. (2021), who noted that while digital tools can foster engagement, their effectiveness is closely tied to usability and alignment with learners' existing experiences.

Moreover, recording tasks contribute directly to scientific literacy. As Kelemen-Finan et al. (2018) suggest, students' confidence in data recording often increases when they understand the value of their contributions to real-world scientific efforts. Whether using a notebook or an app, pupils who perceive their work as meaningful are more likely to feel

capable. In this regard, the AquaInverts app may have had a slight edge by simulating authentic research environments, which could have reinforced students' sense of participation in scientific inquiry.

In conclusion, both instructional approaches effectively supported pupils' self-efficacy in recording macroinvertebrates, with no statistically significant difference in reported confidence. However, the slightly higher mean score in the experimental group points to a potential benefit of digital scaffolding in enhancing procedural clarity and motivation. These findings reinforce the broader view that while technology can aid accuracy and engagement, its true educational value depends on thoughtful design and alignment with pupils' developmental needs and cognitive capacities.

Helping Scientists with Data Collection: Perceptions of Scientific Contribution and Identity Formation

The task of "helping scientists with data collection" acts as a capstone indicator of students' perceived contribution to the wider scientific process and serves as a proxy for their sense of themselves as active participants in research. In both the experimental and control groups, the median self-efficacy score was 4, indicating that most pupils felt confident in their ability to support scientific data collection. Mean scores were closely aligned: 3.76 (SD = 0.97) for the experimental group and 3.87 (SD = 1.08) for the control group. This difference was not statistically significant ($p = .400$), suggesting that both instructional approaches were equally effective in supporting students' confidence in this integrative and aspirational task.

This outcome is encouraging, as it suggests that students across both modalities saw themselves as legitimate collaborators in scientific inquiry. This finding echoes themes from the literature review, where the potential of CS to empower young learners as agents within authentic scientific contexts is emphasised (Makuch & Aczel, 2018; Wells & Leikes, 2006). As Kelemen-Finan et al. (2018) highlight, school-based CS initiatives can strengthen pupils' self-concept as contributors to knowledge when structured activities are supported by adult facilitation, both features present in this study's design.

Although the medians were identical, the slightly higher mean score in the control group may reflect a greater perception of legitimacy when using traditional materials. Paper-based methods, particularly within school settings, are often imbued with institutional authority and familiarity, which may reinforce the seriousness and authenticity of scientific participation. By contrast, while the AquaInverts app was effective in many respects, its digital format may have

appeared more game-like to some pupils, potentially reducing the perceived rigour or realism of the task. This echoes concerns raised by Castagneyrol et al. (2019), who argue that CS activities aimed at children must carefully balance accessibility with academic rigour if they are to be taken seriously by participants.

It is also important to recognise the complexity of this task. "Helping scientists with data collection" is a broad and somewhat abstract concept, which may not have clear or immediate reference points for younger students. As noted in the literature review and supported by Miczajka et al. (2015), pupils' self-assessments of such high-level tasks may be informed more by general impressions than by specific, clearly understood skills. The notable frequency of "Not sure" responses in both groups lends weight to this interpretation.

This task also functions as a cumulative measure, integrating earlier skills, such as observing, classifying, describing, and recording, into a more holistic self-assessment of scientific contribution. As such, the confidence reported here likely reflects an aggregation of experiences across those earlier activities. The broadly equivalent results across groups suggest that both the app-based and traditional approaches effectively communicated the notion of meaningful scientific participation. This supports the conclusions drawn by Cherry and Braasch (2008), who argue that CS can enhance environmental engagement and foster students' identity as eco-citizens, even when gains in self-efficacy are modest.

In conclusion, while the difference between groups was not statistically significant, the high mean scores and consistent medians indicate that both instructional approaches successfully supported pupils' confidence in contributing to scientific data collection. This outcome reinforces the value of well-integrated, curriculum-based CS projects in nurturing a sense of scientific identity, regardless of the mode of delivery. Future developments of the AquaInverts app may benefit from explicitly framing pupils' activities within the broader context of scientific research, thereby strengthening the connection between classroom tasks and real-world scientific contribution.

Summary of Findings Across RQ1 and RQ2

To conclude, the findings across both research questions indicate that the workshop was effective in supporting pupils' engagement and their perceived capacity to contribute to citizen science, regardless of whether activities were delivered through the AquaInverts App or a traditional paper-based identification approach. Overall, both approaches supported positive learning experiences, with differences emerging primarily in the type of engagement and in a small number

of task-specific outcomes. For RQ1, pupils in both groups reported high levels of engagement and perceived learning; however, the paper-based approach was generally associated with stronger affective engagement (particularly enjoyment and excitement) and higher intentions to reuse and share the activity.

In contrast, the app-based approach showed small advantages in usability-related aspects such as readability and perceived ease of identification, while perceived learning remained high across both approaches. Taken together, these findings suggest that digital novelty alone does not guarantee heightened engagement; rather, engagement appears to depend on how the activity supports meaningful participation, social interaction, and developmentally appropriate learning experiences.

For RQ2, pupils across both groups reported moderate to high confidence in their ability to undertake key citizen science tasks, indicating broadly comparable self-efficacy outcomes across delivery modes. Differences between groups were limited and task-specific, suggesting that the workshop context itself, rather than the format of delivery, was the primary driver of pupils' perceived ability to contribute to science. Overall, the results reinforce the value of well-structured, curriculum-aligned citizen science activities in fostering participation and scientific identity, while also highlighting how delivery choices may shape different dimensions of the learner experience.

Chapter 6

Conclusions

The central aim of this study was to examine the educational and emotional engagement outcomes of incorporating CS into EE in a primary school setting. Specifically, the research compared two instructional approaches for macroinvertebrate identification, an app-based approach using AquaInverts and a traditional paper-based approach, to explore how each supported pupils' engagement, perceived usefulness, and scientific self-efficacy in relation to freshwater learning and conservation.

This work is grounded in established educational theories, including embodied cognition, experiential learning, and environmental stewardship, as discussed by scholars such as Wilson (2002), Sobel (1996), and Louv (2005). In doing so, it addresses continuing concerns regarding the increasing disconnection between young people and the natural world. As noted by Mustapa et al. (2015) and Heggen et al. (2019), educational strategies that involve sensory and emotional engagement are essential for fostering ecological understanding and encouraging long-term environmental responsibility.

This concluding chapter synthesises the principal findings and reflects on them through three interrelated sections. Firstly, it addresses the core research questions, providing considered and reflective answers that highlight the practical significance of the findings for educational practice. Secondly, it discusses the limitations of the study, offering a transparent account of the factors that may have influenced the results and their wider applicability. Finally, it presents a set of practical and theoretically informed recommendations intended to guide future research, educational policy, and professional practice.

Taken together, this chapter captures the broader relevance of the study's outcomes, positioning them within current educational and environmental discussions, and emphasising their value in the continued revitalisation of EE.

RQ1 – Digital vs Traditional Engagement: Key Insights

The first research question explored how primary pupils engaged with the AquaInverts app in comparison to traditional paper-based macroinvertebrate identification methods. This comparative analysis examined emotional, cognitive, and behavioural dimensions of learning, and yielded several important insights into the affordances and limitations of incorporating digital tools within EE settings.

Perhaps most notably, the traditional method elicited significantly higher levels of emotional engagement. Students reported greater enjoyment and excitement when using paper-based materials, with average scores for enjoyment and excitement exceeding those for the app. This finding is striking given the increasing prominence of digital learning technologies in primary education. It suggests that sensory-rich, tactile experiences remain powerful in promoting emotional connection and resonance, a key element in EE. These results support Sobel's (1996) position that affective, hands-on interactions with the natural world are foundational to the development of ecological literacy.

At a cognitive level, pupils rated the AquaInverts app slightly more favourably in terms of learning effectiveness, suggesting the digital platform was effective in supporting cognitive engagement. However, learners perceived the content encountered through the traditional method as more meaningful and personally useful. This finding underscores a subtle tension: while digital tools can deliver well-structured, visually clear information, they may lack the contextual richness and authenticity that traditional formats naturally offer. Thus, digital platforms may facilitate cognitive clarity but risk weakening the depth of meaning and relevance that learners derive from the experience.

In terms of usability, pupils noted that the app was easier to read and navigate, yet many found it more cognitively demanding. This paradox reflects the complexity of user interaction with digital environments, while visually clear, such interfaces can still impose procedural challenges that increase cognitive load. These observations are consistent with Mayer's (2005) and Weichbroth's (2020) findings, which stress the need for well-designed educational interfaces that support learners without overwhelming them.

Behaviourally, the traditional method emerged as more effective in cultivating future learning intentions. Students were more inclined to share their experiences and expressed a stronger interest in repeating the activity. These behavioural responses reflect deeper emotional investment and a greater sense of connection. The results resonate with Self-Determination Theory (Ryan & Deci, 2000), particularly the need to support pupils' feelings of relatedness, an important motivator in sustaining engagement and enthusiasm.

Overall, these findings suggest that while digital tools such as AquaInverts hold considerable educational promise, their effectiveness is contingent upon thoughtful, balanced integration into pedagogical practice. Digital interactivity alone does not guarantee greater emotional or motivational engagement. Rather, the most impactful learning experiences

combine digital clarity with the embodied, social, and context-rich aspects of traditional EE.

Practically, educators might consider using digital tools to support individual exploration, reinforce conceptual clarity, and provide structured feedback. At the same time, they should preserve collaborative, hands-on activities that enhance emotional engagement and intrinsic motivation. A hybrid, multimodal approach, attuned to the cognitive, affective, and behavioural needs of learners, offers the most promising path forward for effective EE.

RQ2 – Scientific Self-Efficacy: Key Findings and Significance

The second research question examined the extent to which participation in the EE workshops influenced primary pupils perceived scientific self-efficacy in contributing meaningful data as citizen scientists. This line of inquiry is significant, as cultivating scientific self-efficacy at an early stage can play a critical role in shaping students' long-term motivation, confidence, and engagement with science, particularly within CS contexts that emphasise active participation and authentic scientific processes. The analysis focused on several key scientific tasks, locating, counting, describing, distinguishing, and recording macroinvertebrates, as well as pupils' broader perceptions of their capacity to support real scientists. The results revealed notable differences between the digital (AquaInverts App) and traditional (paper-based) methods, each offering unique educational benefits.

A particularly important finding was that students using the AquaInverts App reported significantly higher confidence in observational tasks, particularly in locating macroinvertebrates in their water sample. The app's structured interface, immediate visual feedback, and interactive design appear to have supported learners by reducing cognitive load and increasing observational consistency. These results are consistent with previous research (Bonney et al., 2009; Hiller & Kitsantas, 2016), which affirms that digital scaffolding can play a valuable role in guiding younger pupils through complex scientific tasks.

In contrast, students using the traditional method demonstrated greater self-efficacy in describing their observations. This finding suggests that paper-based materials, often supplemented with labelled diagrams, structured prompts, and language-rich content, better support the development of scientific communication skills. Given the centrality of language in scientific literacy, particularly in describing processes and phenomena, this highlights a crucial limitation of digital tools: their relative lack of embedded linguistic support. Without this, learners may struggle to articulate their scientific insights in meaningful ways. It therefore

becomes essential for digital applications to more explicitly address language development if
they are to fully support holistic scientific competence.

For tasks such as counting, distinguishing species, and recording data, no significant differences were observed between the two methods. This suggests that, where tasks are clearly defined and appropriately scaffolded, both digital and traditional formats are equally effective. These findings caution against assumptions that one medium inherently outperforms the other; rather, the clarity of instructional design and alignment with learning goals are of paramount importance. Encouragingly, across both groups, students reported comparable levels of confidence in their ability to contribute meaningful scientific data. This shared sense of efficacy reflects positively on the workshop structure and the wider pedagogical design, suggesting that well-framed CS experiences, irrespective of medium, can empower young learners to see themselves as capable contributors to scientific research. This finding reinforces insights from recent literature on children's engagement in CS (Kelemen-Finan et al., 2018; Makuch & Aczel, 2018), highlighting the potential for CS to promote environmental agency and identity formation.

In conclusion, the findings from RQ2 point to a balanced and complementary role for both digital and traditional methods in promoting scientific self-efficacy. Digital tools such as the AquaInverts App are particularly effective for supporting observational accuracy and procedural confidence, while traditional resources provide crucial scaffolding for verbal expression and descriptive skill. Taken together, these insights support the adoption of a multimodal approach to EE, one that integrates the strengths of both formats to nurture the full spectrum of scientific competencies.

Practically, this means that educators should incorporate digital tools where interactive guidance and visual immediacy can enhance learning, while continuing to employ traditional materials to foster descriptive language, reflective thinking, and collaborative engagement. Building scientific self-efficacy in young learners requires this thoughtful integration of tools and pedagogies, ensuring that pupils not only perform scientific tasks with confidence but also develop the communicative and reflective skills needed to participate meaningfully as informed, responsible eco-citizens.

While the findings of this study offer valuable insights into the comparative effectiveness of digital and traditional approaches within EE, it is equally important to

acknowledge the limitations that influenced the research design, execution, and interpretation. As with all empirical studies, this investigation was shaped by contextual and methodological boundaries. A critical reflection on these limitations not only enhances the study's transparency and rigour but also clarifies the scope and relevance of its conclusions. The following section outlines the principal constraints encountered, particularly in relation to the research design, educational context, and the extent to which the results may be generalised.

Limitations of the Study

While this study provides meaningful contributions to our understanding of how digital and traditional tools affect engagement and scientific self-efficacy within EE several limitations must be acknowledged. These span methodological, contextual, and practical aspects and are important to consider when interpreting the findings. Recognising these limitations not only strengthens the transparency and integrity of the research but also offers guidance for future inquiries in this field.

Quasi-Experimental Design and Lack of Randomisation

A key limitation of this study arises from its quasi-experimental design. Although careful efforts were made to match the experimental and control groups in terms of age, academic level, and educational context, true random assignment was not possible due to logistical constraints within the school environment. Consequently, the study remains susceptible to potential selection bias. It is plausible that pre-existing differences between the groups, such as varying levels of interest in science, digital competence, or prior experience with field-based activities, may have influenced the outcomes independently of the instructional approach used.

Contextual Variability and Environmental Constraints

The intervention was implemented within real-world classroom settings, which, while enhancing ecological validity, also introduced a degree of variability that could not be fully controlled. Factors such as class dynamics and differences in classroom layout may have influenced how students engaged with and responded to the learning materials. Furthermore, although the intervention aimed to replicate a field-based experience, all activities were conducted indoors due to logistical limitations. This shift may have diminished some of the sensory and emotional dimensions typically integral to EE, particularly for the experimental

group, which utilised a digital tool originally designed to support outdoor ecological exploration.

Instrumentation and Measurement Equivalence

Another limitation relates to the design and consistency of the questionnaire instruments. While conceptually aligned items were carefully selected to enable comparison between the app-based and paper-based tools, slight variations in wording, introduced to suit the respective digital and traditional formats, may have led to subtle biases in how students interpreted certain questions. Moreover, although the instruments were informed by established frameworks such as the TAM and the CSSES, they were adapted to suit the specific age group and context of this study. These modifications, though essential for developmental relevance, may reduce the extent to which the findings can be directly compared with those from studies employing the original, unmodified instruments.

Sample Size and Generalisability

The study included approximately 153 pupils from 4th Class across three schools in Counties Louth and Monaghan, Ireland. While this sample provided a sufficient basis for meaningful analysis, it is important to note that in one of the participating schools, Latnamard National School, students were drawn from mixed-age classrooms (3rd & 4th and 5th & 6th) due to the small size and rural nature of the school. This reflects a common educational structure in rural Irish schools and adds contextual depth to the study, though it also introduces slight variation in age and grade level among participants. While this does not compromise the integrity of the findings, it should be taken into account when interpreting results. Overall, the specificity of the sample to a particular geographic and socio-educational context limits the broader applicability of the findings. Caution should be exercised when attempting to generalise these results to other regions, age groups, or educational systems. Moreover, as school participation was voluntary, the sample may reflect schools with a stronger pre-existing interest in EE, potentially skewing the outcomes towards a more favourable view of the interventions' effectiveness.

Short-Term Engagement Assessment

Finally, the study assessed students' perceptions and levels of engagement immediately following the intervention. While this offers a valuable snapshot of short-term outcomes, it does not capture any longer-term effects on learning retention, sustained interest in environmental science, or the development of scientific self-efficacy over time. A longitudinal

approach would be necessary to determine whether the instructional methods employed have a lasting influence on students' scientific identity and commitment to environmental stewardship. In summary, although these limitations do not diminish the overall value of the study's contributions, they do call for a measured interpretation of the findings. They also emphasise the importance of further research to explore the durability and wider applicability of the results across more diverse educational settings.

Despite the contextual and methodological limitations of this study, the findings offer meaningful insights that can inform both future research and practice in EE and CS. Conducted within primary school settings, this research contributes to a growing understanding of how such programmes can be thoughtfully designed to nurture ecological literacy, student engagement, and a sense of scientific self-efficacy.

In light of the study's outcomes and limitations, the following recommendations are proposed to guide educators, curriculum developers, and researchers. These suggestions aim to harmonise digital innovation with established pedagogical methods, offering a balanced and contextually relevant approach to environmental learning. By drawing on these insights, practitioners can more effectively support young learners in developing the knowledge, skills, and confidence required for active and informed participation in environmental stewardship.

Recommendations for Future Research and Practice

Drawing upon the findings and limitations of this study, several practical recommendations can be offered to inform future research, educational practice, and the development of digital tools in the context of EE and CS. These proposals seek to strengthen both the educational impact and ecological relevance of comparable initiatives, ensuring that future interventions are not only pedagogically sound but also meaningfully connected to real-world environmental issues.

Design for Blended Engagement: Combine Digital and Traditional Strengths

The findings of this study highlight the distinct yet complementary benefits of both the digital app and the conventional paper-based method. While digital tools proved effective in enhancing observational accuracy and providing cognitive scaffolding, traditional methods appeared to foster greater emotional engagement, richer social interaction, and more expressive language use. Rather than viewing these approaches as competing, future educational

interventions should aim to integrate them in a blended model that capitalises on the strengths of each.

For instance, digital technologies could be employed during the initial phases of exploration to support identification skills and scaffold pupil observation. This could then be followed by more hands-on, collaborative activities that encourage dialogue, reflection, and emotional connection with the natural world. Such an approach has the potential to create a more holistic and engaging learning experience, balancing technological support with the relational and sensory richness of traditional learning environments.

Embed Emotional and Collaborative Features into Digital Tools

Given the comparatively lower levels of emotional engagement noted among pupils using the app, future digital tools in EE should be thoughtfully designed to foster curiosity, collaboration, and personal connection. Features such as narrative frameworks, peer-based challenges, guided discussion prompts, and place-based storytelling can help situate digital tasks within learners' real-world contexts, enhancing both relevance and engagement.

In line with Self-Determination Theory (Ryan & Deci, 2000), the sense of relatedness, feeling socially and emotionally connected, is a key driver of intrinsic motivation. App designers should therefore look beyond functionality alone, considering how digital tools can also evoke emotional resonance and support social interaction, thereby creating a more meaningful and motivating user experience.

Integrate Scientific Language Scaffolding into App Design

A notable limitation of the app was its limited support for the development of descriptive scientific language. To address this, future iterations of educational apps should include features that actively support vocabulary acquisition and model the use of scientific discourse. Tools such as interactive glossaries, language prompts, and structured observation templates can assist young learners in articulating their observations more clearly and confidently.

This is especially pertinent in CS contexts, where the accurate communication of scientific findings is essential. By embedding linguistic scaffolding into digital platforms, educators and developers can help bridge the gap between observation and expression, thereby enhancing both scientific understanding and communication skills.

Broaden Contextual Testing and Longitudinal Evaluation

Due to the study's limited geographical and temporal scope, future research should seek to replicate the intervention across a wider range of educational settings, encompassing rural,
urban, and culturally diverse contexts. This would help to establish the generalisability of the findings and uncover context-specific dynamics that may influence outcomes.

In addition, longitudinal studies would offer valuable insights into the sustainability of the observed changes in pupil engagement and scientific self-efficacy. Such research could explore whether early exposure to CS contributes to enduring environmental attitudes, inspires future interest in science-related careers, or leads to increased involvement in sustainability initiatives. Understanding these longer-term impacts is essential for evaluating the true educational and societal value of such interventions.

Position Children as Co-Creators in Design

To further strengthen ecological identity and ensure educational relevance, future initiatives should consider involving children not merely as participants, but as co-creators in the development of learning tools and content. Employing participatory design approaches can help ensure that both digital and traditional resources reflect children's lived experiences, cultural contexts, and personal interests. Such an approach aligns with the view of children as eco-citizens and active contributors to knowledge production, as emphasised by Heggen et al. (2019). This philosophy is foundational to both CS and transformative EE, recognising young learners as capable and creative agents in shaping their own learning experiences.

In summary, future efforts should move beyond the simplistic dichotomy of "digital versus traditional" approaches. Instead, educators and researchers are encouraged to adopt integrated, context-sensitive pedagogies that engage the full spectrum of cognitive, emotional, and social dimensions of learning. Through such approaches, we can more effectively support children in developing as informed, confident, and connected contributors to environmental stewardship and CS.

Concluding Thoughts

This study has shown that EE and CS can be meaningfully enriched through carefully

designed, age-appropriate interventions that acknowledge both the promise of digital technologies and the enduring value of hands-on, experiential learning. By examining how a mobile application and a traditional paper-based approach influenced children's engagement and scientific self-efficacy, the research has shed light on the educational possibilities and limitations inherent in each method. The findings suggest that no single approach is sufficient in isolation; rather, it is through the thoughtful integration of digital, tactile, emotional, and social elements that the most profound learning experiences emerge.

Beyond the comparative framework, this research addresses a broader educational imperative: the need to reconnect children with the natural world in ways that nurture scientific literacy, ecological identity, and a sense of belonging within the more-than-human community. At a time of deep ecological uncertainty, such pedagogical goals are not merely desirable, they are essential. When children come to see themselves as capable contributors to scientific knowledge and as stewards of the environment, they are more likely to carry those dispositions into adulthood.

Looking to the future, the ongoing development of hybrid learning models, co-designed with and for young learners, holds great potential for both EE and CS. As educators and researchers, our role is not simply to teach children about the world, but to help them learn in, with, and for it. This dissertation represents one step along that path.

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Appendixes

Appendix A: Workshop plan sent to teachers




STRUCTURE OF THE WORKSHOP
WORKSHOP
05 min
INTRODUCTION
Welcome and introduction of the team
30 min
PRESENTATION/EXPERIMENTS
The researcher will present on the topics of water, the planet, and why macroinvertebrates serve as indicators of water quality and also make experiments.
10 min
BREAK
1h30 min
HANDS-ON ACTIVITY
Students will identify macroinvertebrates collected from the stream near the school
30 min
FINAL DISCUSSION
Students will have the opportunity to express themselves, share their experiences, and ask questions.

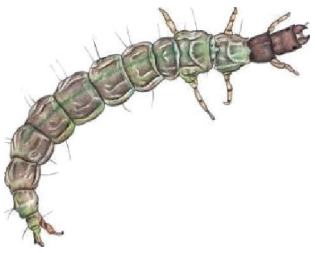
Appendix B: Adapted questionnaire for app evaluation

Tell us what you think about the App
Please tick the most appropriate answer



	Totally agree	I agree	Not sure	Disagree	Totally Disagree
I know what I am usIng Lhe app for					
The AqualnvertS app was fun to use					
The AqualnvertS app was exclong to use					
The information was interesting					
The AqualnveM app v•'as easy to use					
The words In the AqualnvertS app are easy to *read*					
i want to use the AqualnvertS app again					
I learned something new					
Idenbflcation of macroinvertebrates was easy					
I will ask permlssIon to dotvn|oad the AqualnvertS app at home					
I will tell people outside the school about the AqualnvertS app					

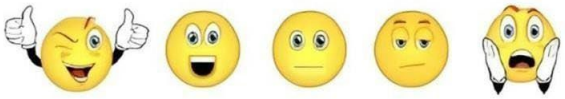




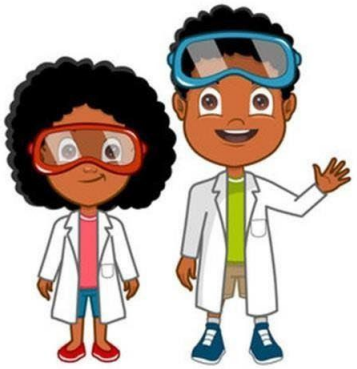
Appendix C: Adapted questionnaire for control group evaluation



Tell us what you think about the Macroinvertebrates identification!
Please tick the most appropriate answer



	Totally agree	I agree	Not sure	Disagree	Totally Disagree
The identification was fun					
It was exciting					
The information was interesting					
The guide was easy to follow					
The words are easy to read					
I would like to do it again					
I learned something new					
Identification of macroinvertebrates was easy					
I will tell people outside of school about the workshop					



Appendix D: Adapted version of the Citizen Science Self-Efficacy Scale (CSSES)



How well can you do the activities listed below?
Please tick the most appropriate answer





	Very well	well	Not sure	A little	Not at all
Locate macroinvertebrates					
Count Macroinvertebrates					
Describe different macroinvertebrates					
Find differences among macroinvertebrates					
Distinguish macroinvertebrates from other animals					
Record macroinvertebrates					
Help scientists with data collection					





Appendix E: Ethical Approval Letter from DkIT and Participant Documentation

DkIT
An Scoil Sláinte & Eolaíochta
School of Health and Science

Samuel Perpétuo Rodrigues,
Centre for Freshwater & Environmental Studies,
Dundalk Institute of Technology,
Dundalk,
Co. Louth

16th February 2024

Re: Aquainverts as a Digital Tool to Engage Children as Citizen Scientists

Dear Samuel,

The above study was discussed at the Ethics Committee on the 28th September 2023. I acknowledge receipt of your amendments dated 9th February 2024. This study is now granted ethical approval. Wishing you the best of luck with your research.

Yours sincerely,

Edel Healy

_____

Dr.Edel Healy
Chair of School of Health & Science Ethics Committee

Cc: Dr. Caroline Gilleran Stephens/Dr. Suzanne Linnane

We are here from H_2O Heroes and would like you to take part in a research project. This information sheet will tell you all about this project. It is important that you read this carefully and make sure that you understand everything so you can decide if you want to take part.

What's it about?

We will be exploring the water from your local river to investigate how clean it is. You will get the chance to become a scientist and carry out real scientific experiments.

What happens if you join?

Get ready for a 2-hour workshop in your classroom full of fun and learning! We'll chat about the environment, and water, and identify and count small insects called macroinvertebrates. We will show you what to do and then we will see how you get on recognising the different macroinvertebrates. We will have some question sheets for you to complete.

Why you?

You were picked because we invited your school to take part in this research project and they said yes!

Are the question sheets a test?

This is NOT a test. There is no right or wrong answer. The questions will be anonymous - this means you do not write your name on it. If you do not want to answer a particular question, it is ok to skip it. In fact, if you don't want to answer any questions at all, that is ok. You can still be a scientist and take part in the workshop.

Why join?

Joining in you'll have the chance to learn exciting things. Not only will you help us improve H_2O Heroes, but you'll also play a part in understanding how to take care of our environment.

Would you like to join the research project?



YES



NO

Dear Teacher,

Research project: AquaInverts as a Digital Tool for Engaging Children as Citizen Scientists.

My name is Samuel Perpetuo, I am a PhD student in the Centre for Freshwater and Environmental Studies (CFES) at Dundalk Institute of Technology.

This letter is to request your participation, along with your class, in a research project on assessing the effectiveness of the H_2O programme in engaging young learners as Citizen Scientists. Specifically, I am examining the potential of children to contribute reliable data to a research database using a digital tool, the 'AquaInverts' App. The results from this study will contribute towards my PhD thesis and are expected to aid in the further development of the H_2O Heroes Environmental Education (EE) programme for primary school children.

I am inviting your class to participate in a H_2O Heroes EE workshop at school. H_2O Heroes offers primary school children the opportunity to become scientists and carry out hands-on, age-appropriate scientific experiments, making science fun, interactive and linked to their everyday environment. The children will be observed while participating and will be asked to complete short pre- and post-workshop questionnaires. I will also be requesting that you and some parents/guardians or other adults at home engage in several questionnaires and a short interview with myself. All the answers both you and your child give will be private and confidential.

Before you decide whether you wish to take part, you should read the information provided below in the participation leaflet. You should clearly understand the **benefits** and **risks** of taking part in this study so that you can make a decision that is right for you.

You can change your mind about taking part in the study any time you like. Even if the study has started, you can still opt out, and you are not required to provide me with a reason. A consent form is attached for you to sign and return as part of the informed consent process. Should you have any questions or would like more details about the study please contact me.

Warm regards,

Samuel Perpétuo

Centre for Freshwater and Environmental Studies (CFES)

Dundalk Institute of

Technology h2oheroes@dkit.ie

Teacher Information Leaflet

Research project: AquaInverts as a Digital Tool for Engaging Children as Citizen Scientists.

You are being invited to take part in a research study, before you decide whether or not you wish to take part, you should read the information provided below carefully. You should clearly understand the risks and benefits of taking part in this study so that you can make a decision that is right for you. This process is known as 'Informed Consent'. You can change your mind about taking part in the study any time you like. Even if the study has started, you can still opt out, and you are not required to provide us with a reason.

Why is this study being done?

This study is part of a PhD study at Dundalk Institute of Technology and will assist in further developing the H_2O Heroes Environmental Education (**EE**) programme for primary school children by incorporating a digital tool in the form of an App 'AquaInverts'.

Why am I being asked to take part?

You are being asked to take part because you are a teacher of 4^{th}, 5^{th} or 6^{th} class and your school has agreed to participate as a pilot school for this project.

What will happen to me if I agree/agree for my class to take part?

To conduct this research, I am inviting your class to participate in a 2-hour workshop facilitated by the H_2O Heroes team in your school. Prior to the workshop, we will send you consent forms to distribute and two questionnaires, one for you to complete and one for the children in your class. We request that both of these questionnaires are completed before the scheduled workshop. During the workshop, the children will be observed conducting the experiment and there will be an in-class questionnaire facilitated by the H_2O Heroes team.

After the workshop, we will send two additional questionnaires, and we kindly ask for your assistance in ensuring that these are completed within 7 days of the workshop taking place. Furthermore, we would like to invite you for a 30-minute interview to gather your insights and perspectives on the workshop and the overall experience.

Timetable of activities

	Pre-workshop (2 weeks)	Pre-workshop (1 week)	During workshop	Post-workshop (1 week)	Post-workshop (4-6 weeks)	Time input
Planning meeting	Teacher					**30 m**
Questionnaire		Teacher				**10 m**
		Students				**10 m**
In-class observation & assessment			Students			**2 h**
Questionnaire				Teacher		**10 m**
				Students		**10 m**
Interview					Teacher	**30 m**

What are the benefits?

H_2O Heroes is an EE programme that offers primary school children the opportunity to carry out hands-on, age-appropriate scientific experiments using real water samples from local rivers ensuring that the experience is linked to their everyday environment. The project offers educational benefits to both children and teachers. Children will get the opportunity to become scientists contributing real data to a research database.

Teachers will have access to a new classroom friendly digital tool, the 'AquaInverts' app. Findings from this project will develop further EE programmes for primary school children to engage them with science and their local environment.

What are the risks?

There will be minimal **risks** involved with participating with this study. While researchers will ensure confidentiality in reporting and research methods to protect an individual's responses within the workshops, there is a minimal risk that the information children share will be shared by other children who might reveal some of the information to other community members who were not part of the workshop. Some students may not want to join and engage in the activities, which can be challenging. The H_2O Heroes team are trained to handle such situations and provide appropriate support.

Is the study confidential?

Yes, identifying information such as name, address, or email will not be attached to an individual's response. When reporting results from this study, precautions will be taken to ensure that information that could be linked to individual participants from the study is either not included or the participant's identity is disguised. The information received from this research study may be kept and used to build upon for further research. However, as stated before, all necessary measures to protect the identity of individuals participating in the study will be taken – including ensuring that information is excluded if it poses a risk of being directly linked to them.

The interviews will be digitally recorded and once they are transcribed into written minutes, all digital records will be destroyed. All data will be stored safely and securely in accordance with the policies at DkIT. Data will be stored on a secure password protected server and the original questionnaires will be stored securely in the Institute's data storage facility for 2 years. Only my supervisors and I will have access to the data. The data will be used for research purposes only. A copy of the findings will be made available to you on request.

Where can I get further information?

If you need any further information now or at any time in the future,

please e-mail: h2oheroes@dkit.ie

Consent Form for Teachers

Research project: AquaInverts as a digital tool for engaging children as citizen scientists

I have read and understood the **Information provided** about this research project. The information has been fully explained to me and I have been able to ask questions, all of which have been answered to my satisfaction.	**Yes** □	**No** □
I understand that I don't have to take part in this study and that I and/or my class can opt out at any time. I understand that I don't have to give a reason for opting out and I understand that opting out won't affect my future.	**Yes** □	**No** □
I have been assured that information about me will be kept private and confidential.	**Yes** □	**No** □
I have been given a copy of the Information Leaflet and this completed consent form for my records.	**Yes** □	**No** □
Storage and future use of information: I give my permission for information collected about me to be stored or electronically processed for the purpose of research and to be used in related studies or other studies in the future but only if the research is approved by a Research Ethics Committee.	**Yes** □	**No** □

I, _____(PRINT NAME) TEACHER

_____

(NAME OF SCHOOL and CLASS)

Please tick the appropriate box:

❒ **YES**, agree to take part in the H_2O Heroes project as a teacher participant.

❒ **NO**, do not agree to take part in the H_2O Heroes project as a teacher participant.

SIGNED: _____Date_____

SIGNATURE OF TEACHER

To be completed by the Researcher:

I, the undersigned, have taken the time to fully explain to the above participants the nature and purpose of this study in a way that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

SIGNED: _____ Date _____

SIGNATURE OF RESEARCHER

Dear Parent/Guardian,

Research project: AquaInverts as a Digital Tool for Engaging Children as Citizen Scientists.

My name is Samuel Perpetuo, I am a PhD student in the Centre for Freshwater and Environmental Studies (CFES) at Dundalk Institute of Technology.

This letter is to request your participation, along with your child's, in a research project on environmental education, building science capital and intergenerational learning. Specifically, I am considering the influence that children have upon their parents/guardians learning and behaviour. The results from this study will contribute towards my PhD thesis and are expected to aid in the further development of the H_2O Heroes Environmental Education (**EE**) programme for primary school children.

I am inviting your child to participate in a H_2O Heroes EE workshop at school. H_2O Heroes offers primary school children the opportunity to become scientists and carry out hands-on, age-appropriate scientific experiments, making science fun, interactive and linked to their everyday environment. The children will be observed while participating and will be asked to complete short pre- and post-workshop questionnaires. I will also be requesting that the teachers and some parents/guardians or other adults at home engage in a short interview with myself. All the answers both you and your child give will be private and confidential.

Before you decide whether you wish to take part, you should read the information provided below in the participation leaflet. You should clearly understand the **benefits** and **risks** of taking part in this study so that you can make a decision that is right for you. This process is known as 'Informed Consent'.

You can change your mind about taking part in the study any time you like. Even if the study has started, you can still opt out, and you are not required to provide me with a reason. A consent form is attached for you to sign and return as part of the informed consent process. Should you have any questions or would like more details about the study please contact me.

Warm regards,

Samuel Perpétuo

Centre for Freshwater and Environmental Studies (CFES)

Dundalk Institute of

Technology h2oheroes@dkit.ie

Research project: AquaInverts as a Digital Tool for Engaging Children as Citizen Scientists.

You are being invited to take part in a research study, before you decide whether you wish to take part, you should read the information provided below carefully. You should clearly understand the risks and benefits of taking part in this study so that you can make a decision that is right for you. This process is known as 'Informed Consent'. You can change your mind about taking part in the study any time you like. Even if the study has started, you can still opt out, and you are not required to provide us with a reason.

Why is this study being done?

This study is part of a PhD study at Dundalk Institute of Technology and will assist in further developing the H_2O Heroes Environmental Education (**EE**) programme for primary school children by incorporating a digital tool in the form of an App 'AquaInverts'.

Why am I being asked to take part?

You are being asked to take part because you are the parent of a child in 4^{th}, 5^{th} or 6^{th} class at a primary school which has already agreed to be a partner school for this project.

What will happen to me if I agree/disagree for my child to take part?

To conduct this research, I am inviting your child to participate in a 2-hour H_2O Heroes science workshop at school. H_2O Heroes is an EE programme that offers primary school children the opportunity carry out hands-on, age-appropriate scientific experiments using real water samples from local rivers ensuring that the experience is linked to their everyday environment. The children will be observed while sorting their samples and will be asked to complete short pre- and post- workshop questionnaires. Some parents/guardians will be asked to engage in a short interview (about 30 minutes) either online/in person. All the answers both you and your child give will be private and confidential.

What are the benefits?

The project offers educational **benefits**. Children will get the opportunity to become scientists contributing real data to a research database. The benefits of taking part in this research study for you may not be immediately noticeable. Participation in this research study will give you an opportunity to share your knowledge. Findings from this project will develop further EE programmes for primary school children to engage them with science and their local environment.

What are the risks?

There will be minimal **risks** involved with participating with this study. While researchers will ensure confidentiality in reporting and research methods to protect an individual's responses within the workshops, there is a minimal risk that the information children share will be shared by other children who might reveal some of the information to other community members who were not part of the workshop.

Is the study confidential?

Yes, identifying information such as name, address, or email will not be attached to an individual's response. When reporting results from this study, precaution will be taken to ensure that information that could be linked to individual participants from the study is either not included or the participant's identity is disguised. The information received from this research study may be kept and used to build upon for further research. However, as stated before, all necessary measures to protect the identity of individuals participating in the study will be taken – including ensuring that information is excluded if it poses a risk of being linked directly to them.

The interviews will be digitally recorded and once transcribed into written minutes, all digital records will be destroyed. All data will be stored safely and securely in accordance with the policies at DkIT. Data will be stored on a secure password protected server and the original questionnaires will be stored securely in the Institute's data storage facility for 2 years. Only my supervisors and I will have access to the data. The data will be used for research purposes only. A copy of the findings will be made available to you on request.

Where can I get further information?

If you need any further information now or at any time in the future,

please e-mail: h2oheroes@dkit.ie

Consent Form for Parents and Guardians

Research project: AquaInverts as a digital tool for engaging children as citizen scientists

I have read and understood the **Information provided** about this research project. The information has been fully explained to me and I have been able to ask questions, all of which have been answered to my satisfaction.	**Yes** □	**No** □
I understand that I don't have to take part in this study and that my child can opt out at any time. I understand that they don't have to give a reason for opting out and I understand that opting out won't affect their future.	**Yes** □	**No** □
I have been assured that information about me will be kept private and confidential.	**Yes** □	**No** □
I have been given a copy of the Information Leaflet and this completed consent form for my records.	**Yes** □	**No** □
Storage and future use of information: I give my permission for information collected about me to be stored or electronically processed for the purpose of research and to be used in related studies or other studies in the future but only if the research is approved by a Research Ethics Committee.	**Yes** □	**No** □

I, _____PARENT/GUARDIAN

Of _____(PRINT STUDENT NAME)

Attending school at _____

(NAME OF SCHOOL and CLASS)

Please tick the appropriate box:

❒ **YES**, give my consent for my child to take part in the H_2O Heroes Project.

❒ **NO**, do not give my consent for my child to take part in the H_2O Heroes Project.

❒ **YES**, I would like to give an interview for the project.

❒ **NO**, I would not like to give an interview for the project.

SIGNED: _____ Date _____

SIGNATURE OF PARENT/GUARDIAN

To be completed by the Researcher:

I, the undersigned, have taken the time to fully explain to the above participants the nature and purpose of this study in a way that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

SIGNED: _____ Date _____

SIGNATURE OF RESEARCHER