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Co-Designing Multimodal Biological Science Learning in Early Childhood Education: Educators' Perspectives and Implementation Experiences

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Abstract

Young learners often have limited access to interactive, engaging, and targeted scientific content in early childhood education. For many years, the focus has been on literacy and numeracy due to the perception that those subjects are more critical in children's overall learning. Drawing on social semiotic theory, this study explores how multimodal resources boost children's engagement and interaction with biological science learning. Twenty early childhood educators across four early childhood centres in Melbourne, Australia, participated in a co-design process to develop and implement eight biological science modules spanning topics around plant growth, soil ecosystems, animal care and the human body. Each module was structured around four sequential learning experiences: inquiry-based exploration (ask and explore), interactive digital games (watch and learn), hands-on activities (try it for real) and Tale-Bot Pro time (screen-free robotic play). Preliminary data via focus group workshops with the educators revealed that they observed children actively participate and engage with the co-designed biological science resources, particularly during the hands-on, experiential, and multimodal robotic play. This research argues that carefully designed multimodal games-based biological science resources can support educators' biological science teaching practices, simultaneously enhancing children's early science engagement and comprehension in early childhood settings. This research also offers practical insight into designing developmentally suitable interactive resources that bridge educators' multimodal play practices, facilitating children's understanding of everyday biological science concepts.

Keywords: early childhood education; biological science; science; multimodality; game-based learning

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1. Introduction

This qualitative co-design research investigates early childhood educators' perspectives on the design and classroom use of multimodal resources for biological science education. The study focuses on educators' resource needs, design priorities, implementation experiences, and perceptions of children's engagement. Hence, this research contributes to educator-informed design principles for connecting digital, hands-on, verbal, embodied, and nature-based biological science experiences in early childhood education.

Past research has examined science education by exploring questions such as 'What is science?' and 'How is scientific knowledge developed?' However, there has been limited

focus on the importance of teaching scientific concepts to younger children in early childhood and early primary education (Trundle and Saçkes 2021). Despite previous studies showing the importance of integrating science into teaching from the early years (Guarrella et al. 2022), there still exists a huge gap in the Australian early childhood and primary curriculum frameworks, with limited access to interactive resources for teaching science concepts to young learners.

It is important to situate this study within the context of both the Australian Curriculum and Early Years Learning Framework as these curriculum documents play a significant role in guiding educators' planning, pedagogy and classroom practices. The Australian Curriculum, Version 9.0, produced by the Australian Curriculum, Assessment and Reporting Authority (ACARA 2025), describes multimodality, in relation to multimodal texts, as the use of two or more modes of communication, such as language, gesture, image, sound and space. It also highlighted that students should learn to understand and create multimodal texts across various learning areas, including science. Also, the EYLF V2.0 emphasises the role of digital technologies and multimedia resources in supporting young learners' learning across linguistic, visual, spatial, tactile, gestural, audio and oral modalities (Australian Children's Education & Care Quality Authority (ACECQA) 2023).

Together, these frameworks provide a curriculum-based rationale for exploring multimodal and digital resources in early childhood science education. However, the EYLF also mentions that educators require ongoing training and support to integrate digital technologies effectively into their teaching practice. This highlights the need for professional learning and contextually relevant multimodal resources that support educators to design engaging and interactive biological science resources for young children.

It is proven that if young learners are engaged with biological science early enough, it will provide them with invaluable opportunities to observe living things, ask questions, classify and compare, explain change, and develop care for plants, animals, and their environments (Miller and Saenz 2021; Roberts 2021). Early experiences in hands-on and experiential science learning can create and shape foundations for later scientific participation, especially because misconceptions in science knowledge are evident from the early years and may persist across formal schooling (Morgan et al. 2016). In addition, early biological science engagement should be understood not only as a preparation phase, but as a way for teachers to support children's curiosity and meaning-making about their living world (Trundle and Saçkes 2021; Fragkiadaki et al. 2023). Furthermore, the EYLF suggests that engaging with living and natural environments supports children's holistic development and helps foster respect and care for their environments.

Internationally, those who have worked with children aged between 3 and 8 years old admit that teaching science fundamentals to young children can be challenging due to their short attention span and abilities in absorbing and digesting complicated scientific concepts (Oaten 2024). The same study suggested that multimodal teaching methods are required to maintain focus and engagement in young learners. Multimodal tools, including various forms of communication, such as text, images, audio, and interactive elements, have proven to increase the potential for enhancing user engagement and understanding of complex concepts in education (Hsin et al. 2014). Considering these technological advances, it is critical to explore various multimodal methods to create a more dynamic learning environment for young learners, enabling educators to overcome the challenges they face in teaching scientific concepts in early childhood settings.

Although science shapes part of the current early childhood curriculum, it often receives less directed attention and focus than other core subjects such as literacy and numeracy. Science education in those early years is usually implemented purely based on educators' curriculum content knowledge, confidence, pedagogical priorities, and access to

suitable resources (Guarrella et al. 2022). In this study, limited access to age-appropriate biological science resources is not treated as an international explanation; instead, it emerged as a concern reported in the literature (Marshall and Brenneman 2016).

It has been noted that there are significant barriers to implementing multimodal and interactive learning tools in the classroom because of a lack of resources, insufficient training for educators, and resistance to adopting new technologies and teaching methods (Aydin et al. 2017). To overcome these barriers, the early childhood landscape needs a coordinated and comprehensive approach that supports early childhood educators through a sustained professional learning journey while also providing age-appropriate and multimodal resources (Guarrella et al. 2022; Kewalramani et al. 2024; Salehi Gahrizsangi et al. 2026).

Creating dynamic learning environments requires the integration of game-based and interactive approaches that actively engage young learners (Ariffin et al. 2014). In response, this research investigates the effectiveness of multimodal and interactive visual communication tools, with a particular focus on gamification and play-based learning, for enhancing biological science education in early childhood settings. The study addresses the persistent underrepresentation and undervaluation of biological science education in the early years, despite its important role in developing children's critical thinking, inquiry, and problem-solving skills. This challenge is further reinforced by policy and curriculum frameworks that often prioritise other learning areas, resulting in limited emphasis on science education during early childhood.

Early childhood science education is created and shaped by an interconnected set of factors rather than by resource availability alone. Important factors such as educators' science knowledge and confidence, pedagogical skills and approaches with regard to young learners' capabilities, as well as opportunities to embed inquiry in everyday play all associate with if and how science is taught (Guarrella et al. 2022; Roberts 2021; Miller and Saenz 2021). Therefore, in this study, understanding access to appropriate resources that can support educators' biological science teaching practice is a significant element within the broader pedagogical context.

Previous studies on multimodality in early childhood education emphasises that young learners make meaning through combinations of speech, gesture, movement, image, sound, and objects, rather than through language alone (Flewitt 2012; Wolfe and Flewitt 2010). However, it also requires researchers to understand how these modes interact with each other and within a specific activity or a learning content area such as literacy or numeracy concepts. In addition, it highlights how various pedagogical choices can make some forms of communication more visible than others (Flewitt et al. 2019). Furthermore, Rowsell's (2013) research draws attention to the obvious meaning-making possibilities of modes and to how modes are orchestrated in practice. In this study, all the perspectives summarised above support analysis of how educators connect conversation, visual representation, physical objects, movement, and hands-on experiential learning coupled with digital interaction in biological science teaching and learning experiences.

1.1. Conceptual Framework

This study is informed by theoretical perspectives such as social semiotics and multimodality to address the current gap in available interactive, multimodal and reliable biological science teaching and learning resources. Social semiotics provides a conceptual lens for examining how meaning is created through different semiotic resources (Lai 2018). Multimodality, on the other hand, means applying different forms of communication, such as language, images, and music, to convey meaning; it includes the interactions and contributions of different modes within various contexts like multimedia, education, and design (Brandt 2004). Using multiple modes of representation together is particularly

appropriate when communicating within the specialised discourse in science classrooms. In these contexts, complex concepts can be more effectively communicated by embedding two or more modes to convey a meaningful science idea. Therefore, written words must also be used to improve content interactivity and learners' engagement.

Previous studies (e.g., Nixon et al. 2015) also show that students must be taught to communicate about biological science in a way that acknowledges the complex nature of scientific concepts. They must be able to determine what modes are being used and how each mode is used. Students should also be able to make meaning (e.g., imagine, understand, learn from, communicate and create) from the modes used in representing scientific concepts. This is important in early childhood science education because young children do not rely only on spoken or written language to understand scientific ideas; instead, they make meaning through play, gesture, drawing, movement, visual representations, as well as interactions with materials. In another study, it is shown that in early childhood settings, multimodal creative inquiry can support children's science meaning-making by enabling them to use embodied, visual, verbal and material modes to explore and communicate scientific ideas (Kewalramani and Veresov 2022).

This theoretical positioning also aligns with the emerging literature on digital and multimodal resources in early STEM education. Previous studies show that digital technologies, educational robotics, interactive games and multimodal educational resources can support young learners' engagement, problem-solving skills, as well as conceptual understanding when they are developed appropriately with educators' guidance (Alotaibi 2024; Nikolopoulou 2022). However, research also shows that the majority of early science resources continue to remain text-heavy with limited interactivity and are rarely relevant for early childhood classrooms, and the focus should be on both cognitive and social skills development for children (Haber and Kumar 2025; Kewalramani et al. 2024). These are directly related to the current study's premise, catering to educators' requirements for age-appropriate science resources and the importance of educator guidance in implementing multimodal and play-based science experiences.

Social semiotics theory explains meaning as a socially and culturally produced phenomenon via the selection and combination of semiotic resources, including speech, image, gesture, movement, sound, objects, and space (Barthes 1964; van Leeuwen 2007). In addition, this perspective is extended by multimodality through analysing how different modes of communication can contribute to different ways of learning. In early biological science education, these modes may work together when children observe an insect, gesture its movement in both real and digital environments, discuss its visible features, arrange loose parts in the classroom to design and create its habitat, or apply pictures and sound to create a learning journey and lifecycle that might be difficult to observe directly. The framework therefore guides educators on how to design and interpret, connect meaning-making learning opportunities across verbal, visual, embodied, material, digital, and spatial modes (Kewalramani and Veresov 2022).

In the current study, both social semiotics and multimodality provide a comprehensive theoretical and analytical foundation for analysing how educators and young learners interact with co-designed biological science resources across various modes of learning, including hands-on, visual, verbal and embodied learning experiences. This study aims to investigate the application of different gamified tools via social semiotic theoretical concepts, while multimodality helps to explore the role of various communication modes in teaching and learning biological science across various early childhood education settings.

In this study, social semiotics and multimodality were selected due to their emphasis on various communicative methods and ability to advance users' engagement (Cirkony and Hubber 2019). Figure 1 shows the conceptual framework guiding this study to understand

perspectives on multimodality for biological science teaching and learning. It illustrates how social semiotics and multimodality can help co-design biological science resources to enhance interactivity and engagement in early childhood education.

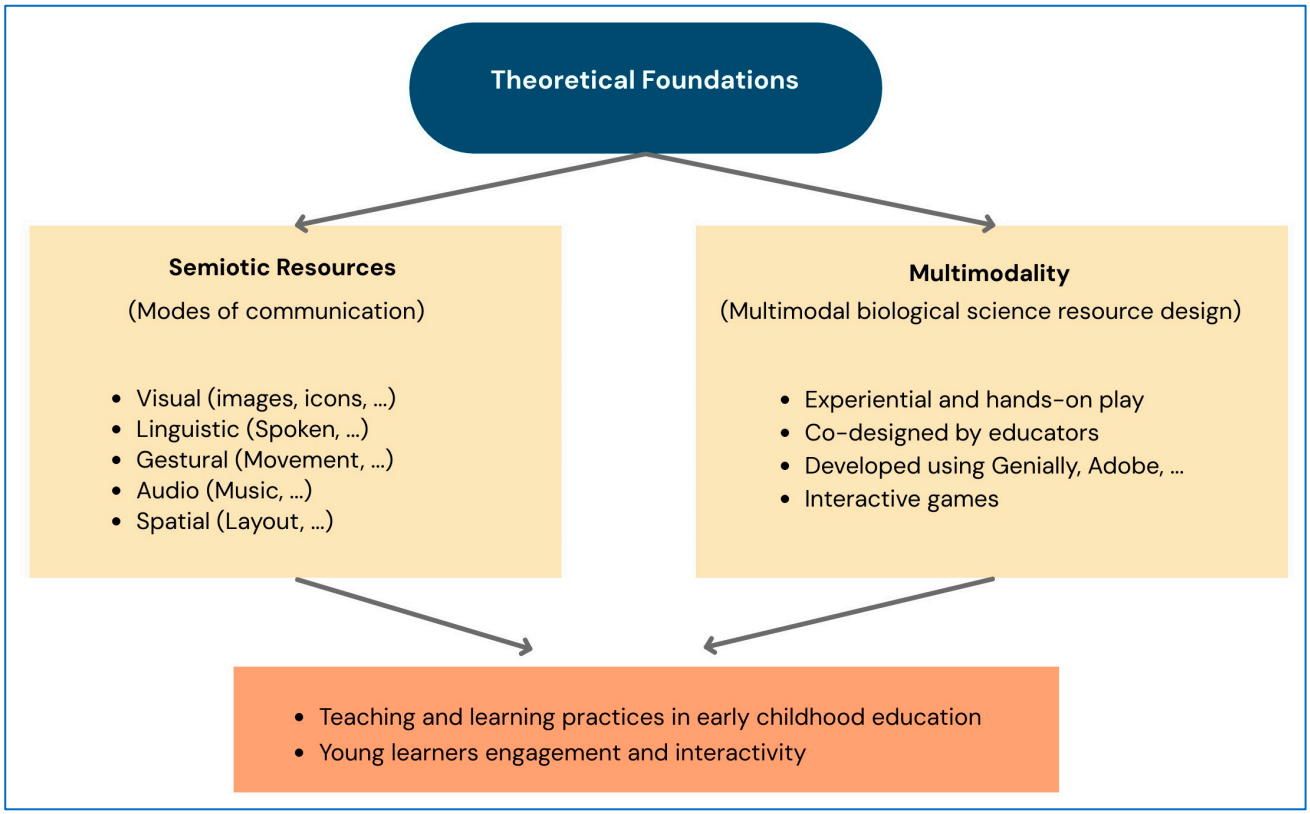


Figure 1. Conceptual framework.

Building on the above theoretical framework, the study addresses the following research question:

How do early childhood educators perceive and experience the co-design and classroom use of multimodal resources for biological science learning?

This question focuses on educators' feedback on biological science resource needs, co-design priorities, implementation of co-designed resources, and perceived pedagogical capability. Professional learning will be examined separately and is not treated as an outcome of this study.

Focusing on multimodality concepts helps address difficulties with integrating multimodal and game-based approaches by analysing the impact of co-designed multimodal content on pedagogical practices and grasping educators' perceptions and practices regarding incorporating biological science into the curriculum. This study also shows the influence of co-designed multimodal content on teaching methods and educators' professional development in implementing multimodal game-based teaching practices.

The overarching goal is to understand how the co-design process of creating interactive and multimodal biological science modules in early childhood education can not only help educators enhance their biological science teaching practices but also student engagement and interactivity. While the focus of this research is on biological science instruction in early childhood (3 years and above), the process of co-design involves educators and researchers working together to create multimodal resources that are meaningful, relevant and effective in improving teaching practices and student engagement.

1.2. Early Childhood Educators Use of Multimodal and Gamified Resources

In recent years, there has been growing interest in multimodal, digital, robotic, and gamified approaches in early childhood STEM education. For example, one study in educational robotics demonstrated that robots (Bee-Bot in this study) can support preschool children's early STEM learning via guided play, sequencing, spatial reasoning, and problem-solving. Similarly, another study indicated that digital technologies could complement early STEM learning by supporting inquiry, creativity, and problem-solving when they are developmentally appropriate and guided by educators (Nikolopoulou 2022). Further research showed that game-based learning can positively influence young children's cognitive, social, emotional, motivational, and engagement outcomes (Alotaibi 2024). These studies together suggest that multimodal and gamified resources can massively enhance early learning experiences, but there persists an ongoing gap in biological science education specifically, as most studies provide limited insight into how early childhood educators select, adapt or co-design biological science resources for their own classroom contexts.

It is proven that the inclusion of science in early childhood education not only depends on educators' access to interactive and age-appropriate content but also on their confidence, pedagogical reasoning, and beliefs about young learners' capacity to participate in the science learning journey (Guarrella et al. 2022; Roberts 2021). Other studies also clearly show that science learning is improved when inquiry is embedded in play, everyday routines, and responsive interactions around children's natural interests (Miller and Saenz 2021; Fragkiadaki et al. 2023).

Other studies showed that nature play can support young learners' biological science learning by encouraging natural curiosity, detailed observation, and engagement with living organisms (Kos et al. 2024). On the other hand, active adult mediation and co-play have been shown to support learning across various digital STEM games. In a different study, researchers show that humanoid AI robots may create interactive and personalised early learning experiences, although challenges remain around cost, teacher training, ethics, and classroom feasibility (Lee et al. 2024). These studies are valuable because they show that children's engagement with science is strengthened when digital, physical, and social modes are meaningfully combined. However, they also show an important limitation in providing clear insights into how educators can integrate digital tools such as games, hands-on inquiry, and multimodal biological science content into a coherent pedagogical sequence.

The co-design approach in this study helped position educators as active partners who identify required and relevant science topics, explain practical limitations, and create the form and sequence of the co-designed biological science resources. Furthermore, this approach considers the design process as a shared inquiry, imagination, and iterative refinement, which are all inseparable components of this study (Sanders and Stappers 2008; Steen 2013). Playful inquiry and co-design, on the other hand, were connected via educators' feedback on how digital, material, embodied, conversational, and nature-based learning experiences could be contextualised within their own settings.

Therefore, this study aims to focus on the existing gap around early childhood educators' perceptions, current practices, and challenges in using multimodal and gamified biological science resources. This study builds on the existing literature by investigating how early childhood educators understand and use multimodal and gamified resources for biological science teaching, and what challenges and supports shape their ability to integrate these approaches in practice. By focusing on co-designed biological science modules, the study addresses a gap between the promise of multimodal STEM resources in the literature and the practical realities of implementing age-appropriate, engaging and biologically focused science learning in early childhood classrooms.

It is crucial to note that this study did not intend to replace children's direct natural world encounters with multimodal resources. Rather, a meaningfully curated and pedagogically sound sequence of digital activities and Tale-Bot Pro experiences were introduced as an interactive and multimodal component within broader learning sequences. Tale-Bot Pro is a screen-free educational coding robot designed for young children with audio recording and dance movement functionalities. In this study, the robot provided children with a medium to tell stories via simple coding, voice recording, and playback. The multimodal premise of the study was that children could program the robot's movement and sequence its actions using its physical controls. These multimodal and gamified features supported collaborative problem-solving, sequencing, explanation of biological science concepts being explored, and imaginative role-play. The science inquiry-related skills also included observation, investigation, exploration, conversation, empathy, and imaginative play. Therefore, the analysis focuses on educators' perceptions of how these modes of learning could complement one another and provide further opportunities for guided inquiry to boost children's overall scientific learning.

The current study also draws upon a previously published scoping review (Salehi Gahrizsangi et al. 2026), where the 5 principles below (Figure 2) have been conceptualised that researchers, pedagogues and early childhood professionals can apply multimodality perspectives while designing games for biological science education.

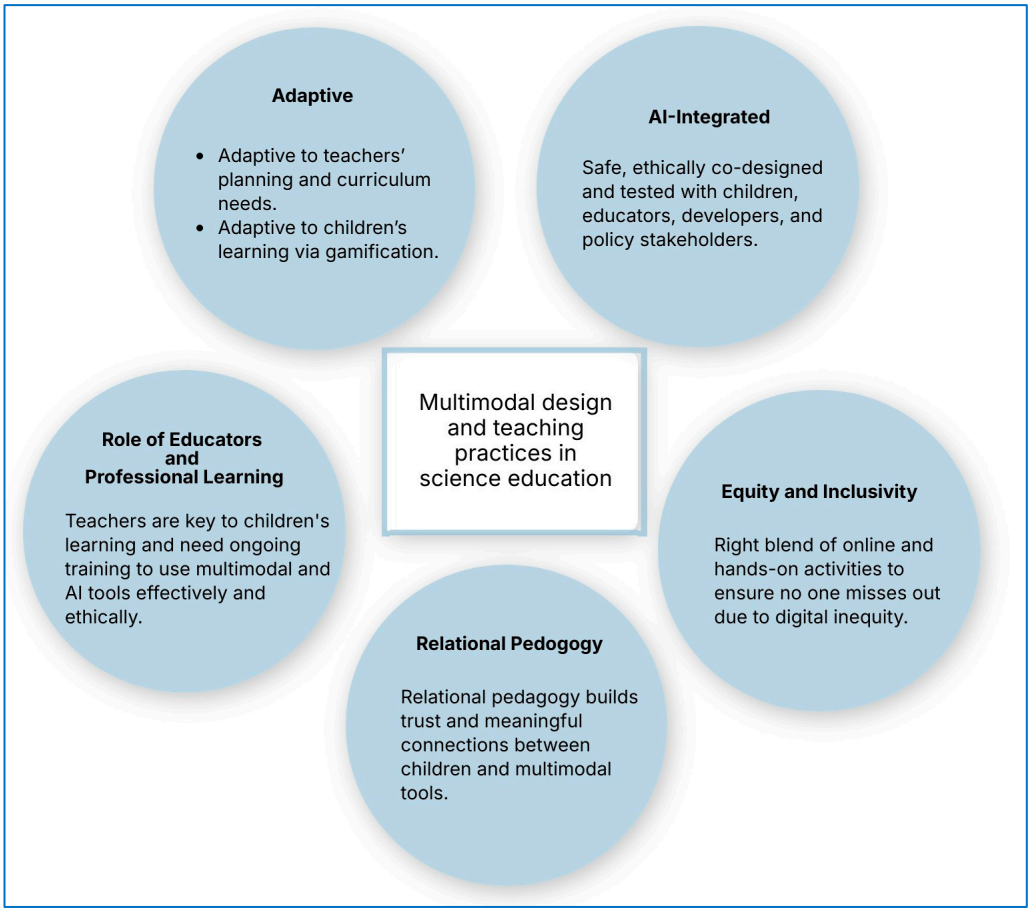


Figure 2. Multimodal design and teaching practices in biological science education.

The multimodal teaching and learning term, that has been used across this study as the overarching concept, refers to the meaningful combination of verbal, visual, auditory, embodied, material, spatial, and digital modes in a connected learning sequence. Within this sequence, interactive games and Tale-Bot Pro time were two additional resources, and

they were not considered separate pedagogical practices or frameworks that sat in siloes. They were employed as two complementary resources within a four-stage teaching and learning multimodal sequence, alongside inquiry and hands-on experiences.

Stemming from that study (Salehi Gahrizsangi et al. 2026), Figure 2's conceptualised framework serves as an analytical framework to guide this research and the future analysis of findings. The framework highlights three interrelated principles below, as deduced from the scoping review of international literature on multimodal and technology- integrated approaches in early childhood science education:

1. Digital and multimodal tools for early science education;
2. The role of educators in facilitating multimodal science learning;
3. Equity, inclusion, and systemic integration of science education.

The above-mentioned principles act as dimensions and serve as an analytical lens, instead of descriptive categories, helping shape how educators' perceptions, challenges, and professional learning outcomes can be understood. The framework supports the exploration of the study's research questions and provides a coherent structure for the focus group discussions, co-design workshops, and reflective practices, ensuring conceptual alignment between the scoping review, the empirical investigation, and the data analysis. The next section discusses the methodology employed in this study.

2. Materials and Methods

This study adopts a qualitative research design to explore educators' perceptions, challenges, and professional development in teaching biological science. It employs a qualitative co-designed methodology involving educators gathering input and insights into developing multimodal and interactive teaching methods.

Findings from the published scoping review reveal that multimodal and technology-integrated science teaching in the early years is not solely about choosing tools; rather, it's mediated by educators' knowledge and skills, pedagogical decision-making, and other systematic factors such as access issues to high-quality resources (Fragkiadaki et al. 2023; Guarrella et al. 2022; Kewalramani et al. 2024; Salehi Gahrizsangi et al. 2026). This study ensured that educators' voices are central to the research, utilising a deeper understanding of their experiences and concerns while supporting the development of impactful multimodal content. Educators are not considered as passive subjects but as active contributors who help co-create knowledge, solutions and resources.

2.1. Why a Co-Design Approach?

A co-design participatory approach aligns with the qualitative research paradigm because of its interpretive nature. It is context-specific as well as collaborative. This method is very effective, particularly in educational settings, due to its shared decision-making for creating resources (IDEO 2020). Participants can share their input to address their concerns by applying a co-construction of knowledge, and this approach creates a bridge between theory and practice. Sanders and Stappers (2008) discuss the evolution of design research from user-centred approaches to co-designing with users. This approach highlights the importance of including future users in the design process if creating quality solutions is the highest priority.

The key aspects of the co-design approach that have been applied in this research are:

1. User as partner: Consider educators as partners and active participants. They were involved in all discussions, prototyping, planning, and implementation. They were treated as true partners.

2. Iterative cycles: The nature of an effective co-design methodology requires multiple rounds of discussions, refinements, and applications. Various cycles of discussions, feedback, and corrections were applied to obtain the best result.
3. Collective creativity: All educators were given an equal opportunity to participate in providing ongoing feedback. By fostering a collective creativity approach, we aim to bring everyone's expertise under one roof.

Participatory co-design is also described as a process of joint inquiry and imagination, where participants engage in creative cooperation to co-create solutions (Nur et al. 2022; Steen 2013). In another study, co-design is expressed as highly effective in addressing context-specific challenges, which is quite relevant to this research due to the complex nature of scientific topics in general (Denzin and Lincoln 2011). In addition, the participatory nature of co-design in this study ensured that the resources were tailored to educators' needs, enhancing their relevance and effectiveness.

2.2. Participants

Upon receiving ethics approval from the university ethics research committee, an expression of interest was distributed via professional networks such as LinkedIn, educational institutions, and online forums to invite qualified and interested early childhood educators. Purposive sampling was considered for this study due to the minimum requirements we had in mind for educators participating in the co-design process. This study focused on children aged 3–6 years, so we needed educators working with this age group only who could share their experiences and challenges. Another requirement was for educators to have at least 6 months' experience in early childhood settings to be able to share their prior experiences, practices, gaps in available resources and expectations from a well-developed tool that fits in their classroom perfectly.

Twenty educators from four early childhood centres across inner and outer suburban Melbourne participated in this study. Participants primarily worked with children aged between 3 and 6 years and had anywhere between seven months and six years of experience within the early childhood education setting. Table 1 provides pseudonyms, age groups, experience, and broad centre-level socioeconomic context. In this table, contextual information is showcased at a high level to support interpretation while ensuring the data protection of individual centres.

Table 1. Demographic information of 20 participating educators.

Early Childhood Centre (ECC)	Educators (Names Are Pseudonyms)	Working with Age Group	Experience in Early Childhood
ECC 1	Kat	3–6	6 years
	Ama	3–4	2 years
	Mor	3–4	1 year
	An	3–4	1 year
	El	4–6	3 years
	Shar	4–6	7 Months
ECC 2	Abh	3–6	6 years
	Dhee	4–6	5 years
	Aa	4–6	8 Months
	Mo	3–4	10 Months

Table 1. *Cont.*

Early Childhood Centre (ECC)	Educators (Names Are Pseudonyms)	Working with Age Group	Experience in Early Childhood
ECC 3	Fran	4–6	3 years
	Ell	4–6	2.5 years
	Jen	3–4	1 year
	Jes	3–5	4.5 years
	Tam	3–4	11 Months
ECC 4	Rho	3–6	4 years
	Mich	4–6	3.5 years
	Jo	3–4	2 years
	Yao	3–4	1 year
	Ka	4–6	1 year

Researchers offered options for both in-person and virtual discussions to accommodate different preferences. We also distributed a formal consent form for data collection as well as video or audio recording. The remaining sessions, including focus group discussions, prototyping sessions and the implementation period, were discussed with the participants to set flexible dates and times that suit their centre the best.

2.3. Data Collection Phases

The outcomes presented in this study (Tables 2 and 3) are based on qualitative educator accounts that were created via recorded focus group discussions, prototyping sessions, educator reflections, implementation of co-designed resources and a final focus group discussion. At no point in this study were children direct research participants. In addition, this research did not use a validated engagement scale, systematic timing protocol, video coding of children, or direct assessment of children's biological science learning. Hence, any reference to children's overall engagement or understanding refers to educators' reported observations and interpretations.

Table 2. Three phases of this study.

Phase	What Do We Do?	Length of the Session	Date and Time	Mode
Phase I	One Focus group discussion	45–60 min	Flexible	Hybrid (we offer both in-person and online options)
Phase II	Two prototyping workshops	30–45 min	Flexible	Hybrid
		30–45 min		
Phase III	III—A: Classroom implementation	6–8 weeks	Classroom implementation and reflective practice (reflective diary)	Implementation and reflective practice. Ongoing support was provided by making classroom visits or online Teams meetings.
	III—B: Final group discussion	60 min	Flexible	Hybrid

Table 3. Structure for the prototyping collaborative workshop session.

Session	Objective	Activities
Session 1: Idea generation	Identify essential components of effective multimodal and gamified resources via analysing their current challenges.	Brief educators on the workshop objectives. Use sticky-note exercises to record educators' ideas on current common challenges and desirable features that match their teaching goals. Conduct general and casual conversations and observations to understand how educators perceive and prioritise technology integration. Each centre was asked to provide two biological science-related topics that they would like to work on as part of this project. As a result, each centre had two topics to work on, and so we ended up with 8 final topics for this project.
Session 2: Prototyping	Create draft versions of multimodal teaching tools, including interactive online games and other resources according to educators' suggestions.	Introduce tools like Genially and H5P for designing interactive biological science content. Facilitate and encourage small groups to develop prototypes, such as digital lessons and games around biological science topics. Explore other gamification strategies suitable for early learners.
Session 3: Evaluation and refinement	Critically evaluate and refine the prototypes and co-create the final version of multimodal resources.	Present sample resources to all participants for collaborative discussions. Build resources in multiple rounds of iterative feedback and discussions

There were three phases within this study, including a focus group discussion, two prototyping sessions and classroom implementation, as well as a final group discussion. The three main phases of this study are summarised below in Table 2. The three phases contributed to data generation in this study. Phase I involved four centre-based focus-group discussions with 20 early childhood educators. Sessions were recorded and lasted anywhere between 45 and 60 min in each centre. During Phase II, two recorded prototyping sessions were conducted at each centre, with each session lasting anywhere between 30 and 40 min. Phase III involved classroom implementation, educator reflection, and a final group discussion. Table 2 maps the participants, data sources, duration, recording status, research-question alignment, and contribution of each source to the reported themes. Tables 2 and 3 map the participants, data sources, duration, recording status, research-question alignment, and contribution of each source to the reported themes.

The first phase explored current perceptions and teaching practices around biological science in early childhood education via focus-group discussions with 20 educators across 4 early childhood centres. These focus-group discussions provided in-depth insights into educators' experiences, teaching strategies, and challenges while uncovering their views on the importance of biological science in the curriculum.

The discussions were driven by the following key questions:

1. Can you briefly explain how you started teaching in early childhood education and what subjects you prefer to teach and why? Their answers helped us understand educators' backgrounds, expertise, motivations, and skills.
2. Can you name and describe a few situations where you have used technology or interactive tools in your classroom? What types of digital tools or games did you use? These questions aimed to discover current practices and preferences regarding multimodal and interactive teaching and learning tools.

3. How important do you think biological science in the early childhood education curriculum is compared with other subjects? By understanding educators' prioritisation of biological science, the study can contextualise its perceived value compared with other core subjects.
4. Do you currently teach biological science in your classrooms? If so, what teaching strategies do you use for this subject? These questions aimed to explore educators' teaching preferences and applied methods in the classroom.
5. How much time do you typically teach biological science in a week? What are some of the most common resources/tools you use to teach biological science? Answers to these questions provided insights into the practical aspects of teaching biological science.
6. How do students generally respond to biological science lessons compared to other subjects? Do they enjoy it? This question aimed to understand students' interest and engagement levels.
7. Can you describe a recent lesson in biological science that was particularly successful or challenging? This question aimed to explore real-world examples of teaching practices and the factors contributing to success or difficulty in delivering biological science lessons.
8. What kinds of professional development or resources do you feel would enhance your ability to teach biological science? The answers pinpointed gaps in current training and resources and inform the development of tailored resources.
9. What role do you think play-based or gamified approaches could have in teaching science? Educators' insights into these approaches could show their perceived value and potential applications in the biological science curriculum.
10. Is there anything else you would like to add about teaching biological science in EC and EP? Would you like to include anything else regarding application of multimodal tools in your classroom? These general questions provided the opportunity to collect more information, uncovering questions that I did not ask or ideas and suggestions that they might have.

The second phase of this study focused on educators' challenges when integrating multimodal technologies and gamified approaches to support the teaching and learning of biological science. Via two collaborative prototyping workshops, we aimed to focus on current hurdles, possible solutions and co-designing resources tailored to educators' needs. Some examples of collaborative prototyping workshop prompts are:

1. What challenges do you currently face when trying to apply multimodal tools in your classroom? What issues do those methods have? These questions are purely focused on the issues that educators face and their ideas around an inefficient tool.
2. What are the key features of a successful teaching tool? Are there specific tools you would prefer not to use with young learners? These questions encouraged educators to articulate the components they value in interactive and engaging resources and identify how they distinguish between good and bad multimodal tools.
3. What are the challenges you face in engaging young students in science topics? Are there any particular topics you would like support for your planning and teaching of science and encourage student engagement? Responses to these questions provided insights into existing practices and highlighted gaps where multimodal or gamified tools could be beneficial.

We also requested each centre to confirm two final biological science-related topics that they would like to work on as part of this research project. Drawing upon Haber and Kumar (2025) study, biological science in this study refers to cognitive learning about living things such as plants and animals' life processes, our bodies, growth stages, interdependence and relationships within environments, as well as nurturing emotional skills. Six co-designed

modules within this study aimed to address these areas of biological science and connected interdisciplinary extensions within the early childhood context of social and emotional learning instead of biological science alone. For example, the 'Where Does It Go?' module is sitting within the interdisciplinary sustainability and citizenship extension. In addition, the 'Feeling Friends' module is placed as a biological science and social-emotional learning connection focusing on children's feelings and regulation of emotions. Therefore, these two modules are not showcased exclusively as biological science.

A summary of finalised topics is provided in Table 4 below.

Table 4. Final topics from each early childhood centre.

ECC and Number of Participating Educators	Final Topics	Classification
ECC 1 6 educators	1. Soil superheroes: An introduction to soil living things: earthworms, ants, and beetles/bugs 2. Where does it go? An introduction to sorting rubbish, recycling, water saving and donation concepts	Core biological science Environmental
		Sustainability Social-Emotional Learning
ECC 2 4 educators	3. Cordy the love link: An introduction to ambilocal cord as a magical connection between babies and their mother 4. Little plant scientists: An introduction to various plant parts and their growth stages	Core biological science Social-Emotional Learning
		Core biological science Environmental
ECC 3 5 educators	5. Buzz buddies: An introduction to garden helpful insects such as honeybees 6. From garden to tummy: A hands-on learning journey about growing, harvesting and tasting simple fruits and vegetables	Core biological science Environmental
		Core biological science Environmental
ECC 4 5 educators	7. Fluffy tails: An introduction to caring for small animals—such as dogs, cats, and rabbits—and how we can look after them. 8. Feeling friends: An introduction to "feelings" such as anger, happiness and excitement and how to navigate them	Core biological science Social-Emotional Learning
		Social-Emotional Learning

We then co-created digital and non-digital learning modules, including various micro-learnings, introducing various biological science concepts via gamified storytelling, visually rich lessons, and interactive questions focusing on the topics we finalised for each centre.

Each module was carefully co-designed in a recurring four-stage sequence. The first stage, 'Ask and Explore', invites children to ask questions, explore open-ended objects in the room, and share and discuss their ideas. The second stage, 'Tap, Watch and Learn', uses a short but very targeted interactive digital experience to support visualisation, prediction, and shared vocabulary. The third stage, 'Try It for Real', systematically transferred ideas into hands-on, embodied, loose objects, or nature-based activities. Finally, the last stage, 'Tale-Bot Pro Time', used a screen-free coding robot for collaborative problem-solving, sequencing, and explanation. In this study and across the eight co-designed interactive modules, the specific modes and activities differed according to the topic and educators' feedback and suggestions; it is noticeable that the digital activity and Tale-Bot Pro were components within the multimodal sequence rather than the conceptual focus of the modules.

For instance, a module on plant growth (titled: little plant scientists) featured gamified storytelling in which children can help a fictional character grow a plant, identifying all

the growing essentials such as air, water and sunlight. We also included interactive visual storytelling lessons, hands-on experiences, as well as exploring the topic further with an educational robot (Tale-Bot Pro) to reinforce their learning journey. Each module was carefully co-designed with educators' needs in mind and included 4 stages of learning with specific instructions for the educators to follow. In addition, the EYLF outcomes were identified and mentioned under each stage.

The third phase of this study explored the effectiveness of co-designed multimodal resources via implementation, observation and a final focus group discussion. In this phase, educators' reflections, observations and recommendations were collected to explore how co-designed multimodal tools support educators' professional development and enhanced student engagement.

2.4. Ethical Considerations and Data Reliability

Ethical considerations informed all stages of this study, from recruitment and data collection to analysis, reporting and publishing. We obtained ethics approval from both Swinburne University of Technology's ethics committee (Ref: 20258220-22266) as well as the Victorian Department of Education (Project ID: 20258220-22266). In addition, in line with the interpretive and co-design methodology, participation was voluntary and based on informed consent.

Furthermore, confidentiality was protected via de-identification of participants, secure storage of digital files, restricted access to data, and careful management of any potentially identifiable information in reports, publications, and presentations. Ethical practice in this co-design project also includes minimising burden and respecting the professional contexts of participating educators.

Audio and video recordings were conducted via Microsoft Teams in both online and in-person sessions, including the auto-generated transcription of each session by the main research facilitator. Initial codes were created from repeated reading by the researchers of the transcriptions, then compared and categorised into broader categories and candidate themes. The main research facilitator (first author) coded each data set in collaboration with the co-authors. Differences in interpretation were identified and addressed via multiple rounds of iterative feedback and discussions, and an audit trail including reflective Word document entries was maintained. Triangulation in this study involved comparing patterns across focus-group discussions, prototyping workshops, and educator reflections. Educators contributed iterative design feedback via co-design and reviewed the final analytic themes.

3. Results

Preliminary data analysis was conducted concurrently with data collection to inform the iterative co-design process. Audio and video recordings, as well as workshop notes and reflections during Phases I and II, were reviewed multiple times to create familiarity with the collected data. Recurring patterns as well as educators' experiences related to multimodal and interactive approaches to teaching biological science in early childhood education were analysed and coded via an inductive thematic analysis approach (Denzin and Lincoln 2011). We then grouped similar codes into wider categories and analysed the data via ongoing discussions, reflection, and further refinements. Themes were deduced that achieved the research aims, keeping in mind the theoretical understanding of multimodality and social semiotics concepts of modes of interactivity afforded by the hands-on activities, experiential games that informed emergent biological science learning amongst children.

3.1. Strategies for Validity and Trustworthiness

Ensuring the credibility, reliability, validity, and trustworthiness of this research was vital. The participatory approach, supported by the literature (Denzin and Lincoln 2011; Sanders and Stappers 2008), ensured that the findings stemmed from authentic learning and teaching facilitated by the educators as real-world experiences within their respective early childhood contexts.

Triangulation was achieved through multiple data sources, including semi-structured interviews, collaborative prototyping, co-design workshops, and educators' reflections, enhancing the reliability and validity of the results. Additionally, maintaining a detailed review and reflective journaling throughout the research process ensured transparency and accountability, contributing to the overall accuracy and credibility of the study.

3.2. Findings and Analysis

Taking into account the full richness of interpretation of educators' thoughts, experiences and interactions with children during their teaching implementation of the games and multimodal activities, the data are presented in the form of several short vignettes (Clandinin 2007). Within the three themes and encompassing vignettes, we flesh out and make meaning of not only what was spoken, but also of the perceived meaning behind the educators' teaching and inquiry-generation moments, interactions and intentional actions with children, gestures, expressions, and what remained unspoken. We present the findings featuring educators' voices as three themes:

1. Educators' perceptions about children's engagement with digital media;
2. Educators' beliefs about multimodal learning and children's playful experiences;
3. Learning opportunities: combination of online and multimodal gaming.

In the following section, we present and analyse the preliminary data as a thematic analysis under the headings of the three themes.

3.2.1. Theme 1: Educators' Perceptions About Children's Engagement with Digital Media

The findings in this study indicated that educators perceived digital media as a potentially valuable tool for supporting young children's biological sciences learning. All the participants highlighted that it was particularly difficult to access age-appropriate resources to support the development of young children's biological sciences understanding. While educators recognised children's strong interest in digital technologies, they reported that access to the content available was limited. For example, Ell, who is a kinder educator, mentioned:

> *"Technology use in our centre is limited to language games like Italian because we focus on Italian culture here. There are a lot of restrictions around technology use and we can't find resources that are age appropriate for our children and easy for them to understand."*

This comment suggests that educators' use of digital media is influenced not only by the availability, but also by the educational setting's philosophy and policies related to the use of technology. Ell's comment also indicates concerns about the technology being developmentally appropriate, which further highlights the willingness of educators wanting to use technology if it were specifically designed for young children's learning abilities.

Mo, who also works as a 3- and 4-year-old kinder educator, highlighted that he found it difficult to access digital resources easily in a manner that was transferable to the early childhood environment. Mitch, another educator who works with older children aged between 4 and 5, mentioned that:

> *"We are lucky if we can find something helpful on YouTube Kids! Our children usually show a lot of interest when we turn on the projector. I wish we had access to better educational digital media rather than looking around on YouTube kids."* (Mitch, kinder educator of children aged between 4 and 5 years)

Mitch's and Mo's comments reveal 2 challenges faced by educators. First, children's enthusiasm for digital media suggests that technology can serve as a highly engaging learning tool. Second, his frustration with the reliance on YouTube Kids indicates the absence of readily available high-quality, age-appropriate resources that are designed for early childhood science. Mitch's comment reveals concern for the quality and relevance of current digital resources available to engage young learners to build scientific knowledge and understanding.

The findings also point to a mismatch between the availability of technology infrastructure and the availability of educational content. All participating educational settings reported access to technologies such as iPads, televisions, projectors and interactive whiteboards. However, these technologies were often used for a limited range of activities. Dhee, who has been a 4-year-old kindler educator for the last 5 years, mentioned:

> *"We use iPads for YouTube videos and Story Park but don't have any other digital resources to use these iPads for! We also have a TV in our Kinder room and children love it when we show them a short video or cartoon during the downtime. It will be great if we can use our TV for educational purpose like teaching them about their body or how a plant grows."*

Comments like this demonstrated that educators were keen to support children's scientific knowledge and learning through multimodal resources; however, they struggle to find age-appropriate digital resources that hold children's interests and provide flexibility and balance to learning environments. Dhee's suggestion that digital media could be used to teach them 'about their body or how a plant grows' demonstrates educators' recognition of the unique capabilities of digital technologies to visually represent biological processes that are difficult to observe directly in the physical environment. Such comments suggest that educators see considerable value in digital technology to support biological science learning through animation and interactive experiences.

Collectively, these findings demonstrate that educators hold largely positive perceptions of children's engagement with digital media, particularly games that have educational content and meaningful learning outcomes. Children's enthusiasm when using projectors, televisions, and iPads was frequently mentioned, indicating that educators regard digital media as a powerful means of attracting and sustaining interest in learning activities. However, educators also expressed frustration that existing resources do not adequately meet the needs of supporting the development of young children's science education. As Mitch remarked, educators often consider themselves lucky if they can find helpful resources on YouTube Kids, which highlights the effort required to identify relevant content that can spark science inquiry moments for children.

Overall, this theme suggests that educators are willing and motivated to integrate digital technologies into biological science learning but are constrained by the limited availability of age-appropriate, curriculum-relevant, and engaging resources. The findings therefore point to a significant gap perceived by educators in children's interest in digital media, educators' pedagogical intentions, and the multimodal resources currently available within early childhood settings. Addressing this gap through the development of high-quality, interactive digital resources could support educators in making more effective use of existing technological infrastructure to enhance young children's engagement with biological science concepts.

3.2.2. Theme 2. Educators' Beliefs About Multimodal Learning and Children's Playful Experiences

This theme revealed educators' commitment to multimodal approaches that support children's engagement with scientific concepts through play-based learning. Educators highlighted the importance of providing accessible and meaningful experiences that enabled children to explore various topics using a range of modalities. However, educators identified challenges related to the use of effective multimodal tools within their teaching practice, such as affordability and access.

Educators frequently described situations in which children demonstrated strong curiosity about scientific topics, yet available resources were insufficient to sustain deeper exploration. For example, Jen, who predominantly worked with children aged between 3 and 4 years old, reflected on the limitations of existing materials when supporting children in gardening and learning about insects:

> *"My children are very interested in topics like gardening and insects but rather than a couple of toy insects and toy gardening tools, I don't have anything else to show them!"*

This comment highlights a disconnect between children's emerging interests and the resources available to support inquiry-based learning. While educators recognised the value of hands-on and multimodal experiences, many felt constrained by a lack of materials that could extend children's engagement and understanding of scientific concepts. Building on this idea, educators expressed a desire for richer learning environments that integrate imaginative play, small world play, and digital learning experiences. Fran from the same early educational setting suggested that multimodal resources could create more immersive opportunities for exploration:

> *"It will be great if we can have some imaginary play spaces and also small world play with insect models and also online activities inspired by insects like honeybees."*

Fran's reflection illustrates educators' belief that learning is enhanced when children can encounter concepts through multiple modes of representation. The combination of physical play materials, imaginative environments, and digital activities was viewed as a way of supporting curiosity, creativity, and deeper conceptual engagement. Educators also emphasised the importance of scaffolded learning experiences that guide children's exploration while maintaining opportunities for active participation and discovery. Other educators also emphasised the need for scaffolded learning activities that can be guided step by step and help children understand a given scientific topic. Shar from another early childhood centre mentioned:

> *"We really value tools that allow children to visualise and create but these tools are expensive. We need something that is affordable, easy to use but interesting for children at the same time."*

This quote reflects a recurring concern regarding equity and accessibility. Although educators recognised the pedagogical potential of multimodal technologies and creative learning tools, financial constraints often limited their ability to implement such resources within their classrooms. Consequently, educators advocated for solutions that balance educational value with affordability, usability, and child-centred engagement.

Overall, findings from this theme suggest that educators view multimodal learning as a powerful means for supporting children's playful exploration of scientific concepts. Their reflections indicate a strong preference for resources that combine physical and digital elements, while also providing appropriate scaffolding to facilitate learning. At the same

time, educators emphasised the need for affordable and accessible tools that can be readily integrated into everyday practice. Collectively, these perspectives informed the design considerations and resource priorities identified throughout the collaborative prototyping process. Table 5 provides holistic information about this theme.

Table 5. Educators' beliefs about multimodal learning and children's playful experiences.

ECC and Number of Participating Educators	Reflection Summary Examples from Educators' Collective Feedback
ECC 1 6 educators	• Educators prefer hands-on and interactive materials, with technology use limited to group activities and short sessions. • Real-life examples, such as exploring "where the rubbish goes", were discussed as effective ways to engage children.
ECC 2 4 educators	• They value tools that allow children to visualise and create but note that real tools can be expensive and creating a balance between digital and non-digital tools can be a challenge. • Children often ask about babies' various growth stages, and educators struggle to find appropriate multimodal educational resources.
ECC 3 5 educators	• Educators expressed interest in topics like gardening and insects, emphasising the importance of covering native Australian insects as well. Educators, however, need enough hands-on activities to encourage children's play-based learning. • Educators suggested including imaginary play spaces, small world play with insect models as well as various art activities inspired by insects.
ECC 4 5 educators	• They raised interest in topics related to care for animals, gentle approaches and linking to nature. They expressed that it has been extremely hard for them to design a balanced learning journey including both digital and hands-on activities. • Educators prefer multimodal resources focusing on various emotions and how to identify and control them. They believe children have various ways of expressing their emotions, hence the need for multiple modes of learning to introduce this important topic.

3.2.3. Theme 3. Learning Opportunities: Combination of Online and Multimodal Gaming

The third theme focused on educators' feedback around the effectiveness of interactive and multimodal co-designed biological science resources. Specifically, this theme explored how the integration of multimodal and digital learning experiences supported educators' teaching practices with a focus on enhancing children's engagement and understanding of biological science concepts. Educators viewed the combination of online gaming, hands-on activities, and multimodal learning experiences as highly valuable for supporting perceived sustained engagement and scientific exploration.

A key finding was the importance of providing scaffolded learning opportunities that enabled children to engage with a scientific topic across multiple experiences and contexts. Educators reported that the co-designed resources allowed them to build upon children's interests over time, rather than relying on isolated activities. Mor, an educator working with 3- and 4-year-old children, explained:

> *"I love the fact that we could scaffold activities around the same topic. My children loved the Tale-Bot Pro, and we had many interesting discussions about coding the robot to collect all the essentials for a plant growth.!"* (Figure 3)

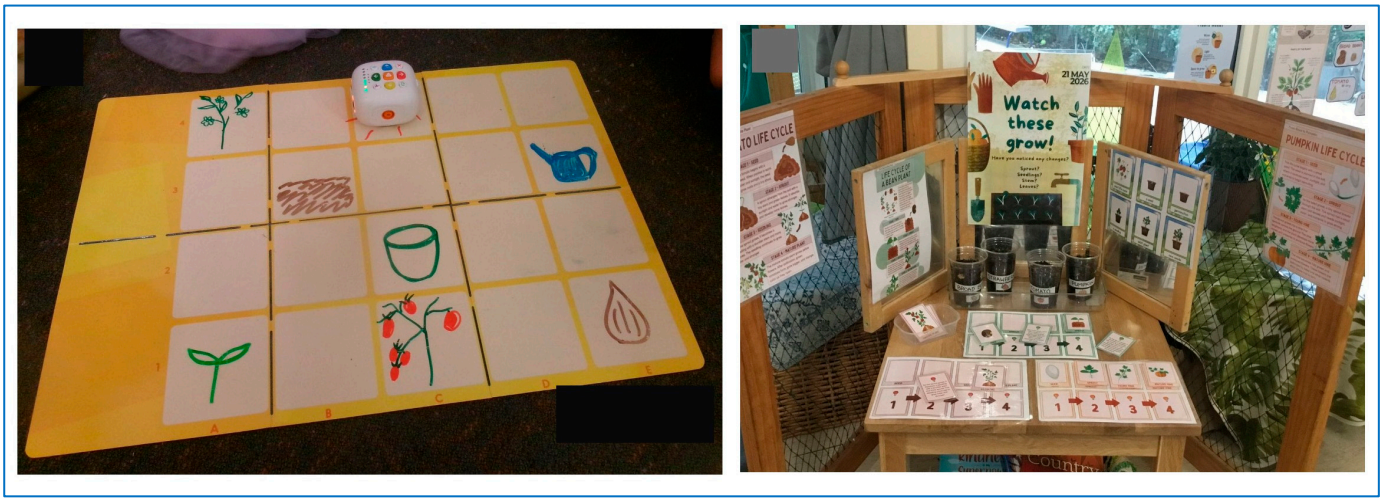


Figure 3. Tale-Bot Pro in "little plant scientist" interactive learning module.

Fran from another centre mentioned:

> *"Children loved recording their own voices in the robot and playing it back when it reached its destination! When we coded the robot to act as a honeybee and travel between flowers to collect nectars, I could see the joy in their eyes when the robot (acting as honeybee) finally collected all the nectars and made so much honey at the end!"*

Mor and Fran's reflections suggest that the integration of digital technologies within a broader sequence of learning experiences supported both a perceived engagement and discussion with children. Rather than functioning as standalone tools, multimodal resources such as Tale-Bot Pro created opportunities for children to revisit and deepen their understanding of scientific concepts through repeated interactions, conversations, and collaborative inquiry. Educators also highlighted the value of combining digital gaming experiences with hands-on, nature-based learning activities. For example, a module that we co-designed with the intention to introduce children to the umbilical cord as a connection between mother and baby (Cordy the Love link) was addressed as a great resource because it connected children's online learning with more exploration and play. Tam from another centre then said:

> *"Cordy the love link was incredibly useful. Children enjoyed the activities in the classroom. They also loved playing the digital game. They laughed a lot and discussed about the character for a long time. It would be great if we could include more resources like this!* (Figure 4)

This observation illustrates educators' belief that meaningful learning occurs when children can engage with scientific concepts through multiple modes, including physical, digital, and environmental experiences. The combination of garden-based activities and digital gameplay appeared to strengthen children's interest in biological science topics, while also encouraging connections between virtual and real-world learning contexts. Educators further suggested that expanding such resources to include additional topics, particularly those relevant to local ecosystems and native species, would provide further opportunities for contextualised science learning.



Figure 4. An educator showcasing "cordy the love link" to the classroom.

Educators emphasised the need for scaffolded learning activities around more biological science topics that can be co-designed step by step to help children understand a given topic. For instance, Shar from another early childhood centre mentioned:

> *"Science activities are conducted at least once a week in our centre, with frequency depending on children's interests and classroom dynamics. We often struggled getting children to focus as they started wandering around in just 3 to 4 min. These activities really helped us keep the children involved in discussions without getting them tired or bored. It will also be great if we can include other biology topics like how animals look after their babies or how children can maintain a healthy diet! Children ask a lot of questions, and we do not have many resources!"*

Shar's comment suggests that interactive multimodal learning experiences may offer an effective strategy for supporting children's concentration and participation in scientific discussions, but we need to expand these resources to include more topics. By incorporating visual and digital elements, the co-designed resources appeared to hold children's interest for longer periods and to facilitate ongoing conversation around scientific concepts.

Overall, findings from this theme demonstrate that educators perceived the combination of online gaming and multimodal learning experiences as a powerful approach for supporting early biological science education. The co-designed resources reported by educators enabled them to scaffold learning across connected experiences, integrate digital and hands-on activities, and maintain children's engagement. These findings highlight the potential of collaborative design processes to generate resources that are pedagogically relevant, engaging for young learners, and responsive to the practical needs of early child-

hood educators. Table 6 provides a holistic view of educators' views and beliefs about multimodal learning opportunities for children using science games.

Table 6. Learning opportunities: Combination of online and multimodal gaming.

ECC and Number of Participating Educators	Reflection Summary Examples from Educators' Collective Feedback
ECC 1 6 educators	• Educators highly valued the co-designed resources and suggested activities because children could revisit the same topic through digital play, Tale-Bot Pro activities and casual discussions. • Educators mentioned that the combination of hands-on activities and digital and robotic play helped maintain children's engagement and supported better classroom discussions.
ECC 2 4 educators	• It was reported that multimodal activity structure helped educators introduce complex biological science topics in a simpler and more eye-catching way. • Educators highly valued activities spanning watching and listening to doing and questioning.
ECC 3 5 educators	• Educators expressed that children were more interested and engaged when learning was combined with multiple modes rather than one long discussion. • Educators mentioned that children struggled with coding the Tale-Bot Pro in the beginning, but they discussed the issues, found possible solutions and celebrated after completing each mission. This was a true learning journey according to the educators.
ECC 4 5 educators	• Educators shared that having multiple modes of engagement and various activities included under each topic helped them with a more crowded classroom. Children were involved with one activity at a time, then rotated groups to try another activity. • Educators perceived that children's attention span was increased, especially when hands-on and Tale-Bot Pro activities were introduced.

4. Discussion and Conclusions

This study investigated early childhood educators' perspectives on the use of multimodal, digital and gamified resources for biological science education. The preliminary findings suggest strong support for approaches that combine visual, digital and play-based forms of learning. Across all three themes, educators emphasised the need for age-appropriate, engaging, and accessible science resources that align with young children's interests and ways of learning. The findings contribute to the growing body of evidence that multimodal and gamified approaches can enhance engagement with science concepts in early childhood settings while also highlighting the practical challenges educators face in implementing such pedagogies.

The first theme revealed that educators generally viewed digital media positively and recognised its potential to support biological science learning. However, participants reported significant difficulties in locating developmentally appropriate and curriculum-relevant digital resources. This finding is consistent with previous research suggesting that although digital technologies can enhance children's engagement, problem-solving skills, and conceptual understanding, many available STEM resources remain poorly aligned with early childhood contexts (Alotaibi 2024; Kewalramani et al. 2024). The educators' comments demonstrate a gap between the availability of technological infrastructure and the availability of quality educational content. Most centres had access to iPads, projectors, televisions, and interactive technologies, yet these tools were often underutilised because suitable science resources were unavailable. This finding extends existing literature by

highlighting that access to technology alone is insufficient; meaningful integration depends on resources that are specifically designed for young children and aligned with early childhood pedagogies.

From a social semiotic perspective, educators' desire for visualisations of biological processes such as plant growth and human body systems is particularly significant. Social semiotics argues that meaning is constructed by multiple semiotic resources rather than language alone (Lai 2018). Biological science concepts are often abstract and difficult for young children to observe directly. Consequently, digital animations, images, movement and sound modalities afforded via interactive games, and visual representations can function as important semiotic resources that make otherwise invisible processes accessible and meaningful. The educators' reflections suggest that they recognise the value of these modes for supporting scientific understanding, even though suitable resources are currently limited. Their experiences reinforce the argument that science education benefits from multimodal representations that combine visual, verbal, and interactive elements to communicate complex concepts effectively (Brandt 2004; Nixon et al. 2015).

The second theme highlighted educators' strong commitment to multimodal learning and play-based science experiences. Participants consistently advocated for learning environments that integrate physical resources, imaginative play, digital technologies, and opportunities for exploration. These findings align closely with multimodal theory, which suggests that learning occurs through interactions among diverse communicative modes, including gesture, movement, visual representations, language, and material artefacts (Brandt 2004). Educators' requests for insect models, imaginative play spaces, gardening resources, and digital activities indicate an understanding that children learn science most effectively when concepts can be experienced across multiple modes. Rather than viewing digital technologies as standalone teaching tools, participants saw them as one component within richer multimodal learning environments.

These findings are also consistent with research by Kewalramani and Veresov (2022), who found that multimodal creative inquiry supports young children's science meaning-making by enabling them to communicate and explore ideas through embodied, visual, verbal, and material modes. The educators in this study recognised that children's curiosity about topics such as the human body, emotions and plant growth cycles could be extended through a combination of hands-on and imaginative play, digital experiences and simple robotic play activities, all of which have the potential to spark children's scientific imagination. The games-based learning approaches identified in this study reflect the inherently multimodal and play-based nature of early childhood learning environments. Educators' experiences revealed how children construct knowledge through physical interaction, observation, movement, and social engagement rather than through text-based instruction alone. The findings therefore reinforce the importance of providing multiple pathways for scientific exploration that build upon children's existing interests and experiences, with games-based learning as a promising approach for fostering a love for biological science learning.

A further contribution of this study relates to the role of affordability and accessibility in resource implementation. While educators valued multimodal tools, many expressed concerns about cost and usability. This finding extends existing discussions within the literature by highlighting that successful adoption of multimodal science resources requires consideration of practical constraints faced by educators. The effectiveness of innovative educational resources depends not only on their pedagogical design but also on their accessibility, affordability, and availability of reliable internet access within real-world early childhood settings. As the EYLF V2.0 recognises, educators require ongoing support and professional learning to integrate digital technologies effectively into practice. The current findings suggest that affordable, easy-to-use, and curriculum-aligned resources may help

reduce barriers to implementation while enhancing educator confidence, thereby supporting more equitable science teaching and learning opportunities within early childhood settings. Additionally, the integration of digital games, hands-on activities, and multimodal learning opportunities can enable them to scaffold learning across multiple experiences and sustain children's interest over time. This study supports the literature demonstrating the educational potential of game-based learning and interactive technologies for promoting engagement and conceptual understanding in STEM education (Alotaibi 2024; Nikolopoulou 2022). Importantly, the findings suggest that gamification can be most effective when embedded within broader inquiry-based learning experiences rather than used in isolation.

The success of the co-designed resources can also be interpreted through the lens of social semiotics and multimodality. The Buzz Buddies resources provided children with opportunities to engage with scientific concepts through multiple semiotic modes, including digital gameplay, physical exploration, discussion, observation, and creative activities. Such experiences allowed children to construct and communicate meaning in ways that were developmentally appropriate and engaging. Consistent with Nixon et al. (2015), the findings suggest that science learning becomes more meaningful when learners can interact with and interpret concepts through multiple forms of representation. The integration of gaming elements appeared to further enhance engagement by encouraging active participation, inquiry, and discussion rather than passive content consumption.

The findings also highlight the importance of educators' involvement and professional digital judgement in facilitating multimodal and gamified learning. Although children responded positively to digital and interactive experiences, educators play a critical role in scaffolding discussions, extending inquiry, and connecting learning across physical and digital contexts. This supports previous research indicating that digital technologies are most effective when used purposefully and guided by knowledgeable educators (Alotaibi 2024; Nikolopoulou 2022). The success of the co-designed resources therefore reflects not only the design of the tools themselves but also the pedagogical practices that surrounded their implementation.

Although this study relied on qualitative findings, there is a case to be made in early childhood pedagogy that multimodal and gamified approaches hold considerable promise for strengthening biological science education in early childhood settings. The findings address both research questions by showing that educators face challenges related to resource availability, affordability, and professional support, while also demonstrating that co-designed multimodal resources can enhance educator practice and children's engagement with biological science concepts. Consistent with the principles of social semiotics and multimodality, the study highlights the value of providing young children with opportunities to explore science through interconnected digital, visual, verbal, embodied, and hands-on experiences. Ultimately, the findings suggest that the development of accessible, curriculum-aligned, and play-based multimodal resources may help address the longstanding underrepresentation of biological science education in the early years and support more meaningful science learning experiences for young children.

This study brings home that educators play a critical role in channelling young learners' interests, particularly in those early years, underscoring the importance of ongoing professional development in early childhood settings. Considering the current gaps in the availability of interactive and multimodal biological science teaching and learning resources in early childhood education, with a huge focus on other core subjects such as literacy and numeracy, it is crucial to co-create resources that not only address biological science gaps but also encourage educators to use multimodal resources to enhance the teaching and learning experience in their classrooms. This study recommends further mixed-methods research to provide an applicable solution by co-creating multimodal, interactive and game-

based biological science resources that incorporates both educators' and children's voices, with the goal of fostering a genuine and enduring enthusiasm for science learning among young children.

5. Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study utilised a small purposive sample drawn from only four early childhood centres, which may limit the transferability of the findings to other diverse early childhood education contexts. Second, participation was voluntary, creating the possibility of self-selection bias, whereby educators with a stronger interest in science education, digital technologies, or innovative pedagogies may have been more likely to participate. As a result, the perspectives represented may not reflect those of the broader early childhood educator population. Third, the study relied primarily on educator self-reports of children's engagement and learning, rather than direct measures of child learning and engagement outcomes. While educators are well positioned to observe children's responses to learning experiences, self-reported perceptions may be subject to personal interpretation. Additionally, children's positive responses to the co-designed resources may have been influenced by novelty effects, whereby engagement is heightened due to the introduction of a new and unfamiliar resource rather than the inherent effectiveness of the intervention itself. Finally, the study did not include direct assessment of children's biological science knowledge, scientific thinking, or long-term learning outcomes, limiting conclusions about the extent to which the resources influenced conceptual understanding beyond observed engagement. Future research employing mixed methods designs, larger and more diverse samples, and direct child outcome measures would strengthen the evidence base regarding the effectiveness of multimodal and gamified approaches in early childhood biological science education.

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Conflicts of Interest: The authors declare no conflicts of interest.

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