frontiers | Frontiers in Education

ORIGINAL RESEARCH
published: 22 July 2022
doi: 10.3389/feduc.2022.933436

Snailed It! Inside the Shell: Using Augmented Reality as a Window Into Biodiversity

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OPEN ACCESS

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Specialty section:
This article was submitted to STEM Education, a section of the journal Frontiers in Education

Received: *30 April 2022*
Accepted: *20 June 2022*
Published: *22 July 2022*

Citation:
Merino C, Iturbe-Sarunic C, Miller BG, Parent CE, Phillips JG, Pino S, Garrido JM, Arenas A and Zamora J (2022) Snailed It! Inside the Shell: Using Augmented Reality as a Window Into Biodiversity. Front. Educ. 7:933436. doi: 10.3389/feduc.2022.933436

Snails have occupied an important role in the ideology and religion of the ancient American peoples, who considered them to be magical and used them in ritual ceremonies as ornaments, musical instruments, and architectural elements. Today, they are a valuable study system for understanding biodiversity and evolution due to their remarkable ecological and morphological diversity. Given that many endemic snails are of conservation concern, and that most South American species are poorly studied, there is a need to engage the public through understandable and scientifically based language, conveying the importance of biodiversity. However, not all biodiversity can be seen with the naked eye. Herein, we describe how we utilize snails and their shells to engage citizens and train teachers to promote the many different facets of biodiversity. Through design-based research oriented toward educational innovation, we created a teaching–learning sequence with immersive technology through the following stages of work: (1) produce a teaching–learning sequence and accompanying mobile device application (for Android on GooglePlay), (2) evaluate the impact of the educational resource, and (3) conduct research through a pre- and posttest design on the learning outcomes of participants. In this work, we first present the field experience where scientists, teachers, and pre-service teachers worked together to find snails from northern Chile to Chiloé Island. Some results from this research stage are: criteria for designing a teaching–learning sequence (e.g., how to utilize place as an opportunity for learning science with developmentally appropriate technologies identified for every phase of the sequence), modeling relevant phenomena about biodiversity and ecosystems through snails, scaffolding for teachers implementing the sequence, and activities that enhance STEM education. A teaching–learning sequence that addresses snails as study objects for 4th grade is presented and validated, allowing us to continue the next phase of our research with schools. A second article will propose results from implementation, iterations, and their implications.

Keywords: snail, augmented reality, biodiversity, territory, teaching-learning sequence

INTRODUCTION

The global onslaught of socio-environmental problems necessitates an imminent focus on science education to promote change and equip today's youth to face the challenges ahead (Tasquier et al., 2022). Therefore, science educators have a key role in supporting students to make informed decisions and take action to mitigate unfortunate phenomena, such as global warming and pollution, among many others. Educational experiences focused on these present-day issues should aim to help students comprehend their causes and effects, as well as to make pedagogical decisions that have optimal odds of motivating students to take actions based on scientific data (Skamp et al., 2013). To search phenomena and educational resources that enable students to study socially controversial phenomena can be complex, given the inter- and intradisciplinary components that it carries. However, studies in STEM education give us resources and tools to think and find solutions to address it in the classroom (Bybee, 2013). STEM educators require resources that integrate and address socio-environmental and territorial phenomena and their relation with reference school science models (García et al., 2022). Despite this, there is a dearth of resources that explore relevant and timely issues affecting our world, especially in local contexts. To address this, we use a unique and seemingly unlikely subject: snails. Snails can be found in a variety of habitats across different landscapes, and can be easily collected by teachers and students without prior training in handling techniques. We raise the opportunity of taking snails as a window into biodiversity that can be explored in the educational context through technological resources, such as augmented reality.

This research contribution is an educational resource whose design contemplates a teaching-learning sequence (TLS) about snails that includes immersive technologies supporting the development and promotion of the students' capability to visualize, given the inter- and intradisciplinary aspects of science, technology, engineering thinking, and mathematics, which are put in action for real-world problem-solving. We incorporate scaffolds for teachers to implement the sequence and activities for students to connect and learn with the natural world through a scientific experience (González et al., 2020). Those activities will enhance STEM education abilities in students, specifically asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, obtaining, evaluating, and communicating information (Lee et al., 2014). Additionally, authentic STEM activities increase students' capacity to solve problems, communicate their knowledge, and grasp legal, social, and ethical dilemmas in digital environments (MINEDUC, 2019).

We selected snails as an educational tool for several reasons. First, their shells are durable, calcareous structures that can persist in some environments long after the snail has died. This leaves behind a valuable tool for researchers studying ecological communities of the past, and can provide evidence for changes in species abundance and community structure over time (Hirano et al., 2019; Jochum et al., 2021; Breure et al., 2022), and thus evidence of environmental change in a particular area. Second, snails have important roles in the trophic ecology of many ecosystems (Parent and Crespi, 2009; Kraemer et al., 2019; Hirano et al., 2020). Many birds, fish, and other species depend on snails as an important part of their diet (Smith, 1966; Schilthuizen et al., 2006; Parent and Crespi, 2009). Most species of land snails consume fungi and leaf litter, helping with decomposition, and many are carnivorous, helping to keep other species in check. Third, land snails often have typically restricted habitat requirements. Therefore, we can use their presence, absence, and abundance over time to detect subtle changes that humans might not be able to see until it is too late. Fourth, several species of land snails live in small geographic areas, and since there are so many species, it makes them fascinating to study how life on Earth evolved. And finally, snails are an important piece of the puzzle that makes the planet work. Understanding their role in the grand scheme of things can also help us to better understand how to avoid their extinction (Régnier et al., 2009; Haponski et al., 2017; Hirano et al., 2018), and in a roundabout way, ours as well. From our experience of utilizing snails as a vehicle to engage in scientific thinking, we have identified ways in which the natural accessible environment can be experienced and then understood at a deeper level through technological enhancements and supports, which ultimately lead to student learning.

This study aims to develop a resource that utilizes a TLS, including immersive technologies that support the development and promotion of visualization capabilities in students. Snails effectively support inter- and intradisciplinary aspects of science, technology, engineering, and mathematics (STEM) that can then be put into action to solve problems. The scope of this study looks for addressing a science education issue through the interdisciplinary integration of different expertise (ecology, geography, IT, education, and statistics), allowing to amplify its meaning, and this same working logic can be successfully applied in search of solutions to scientific problems addressed in a territorial and contextual manner in school.

The article has been divided into different sections corresponding to the methodology selected for the foundation of a new TLS design. First, we provide some guidelines on how design-based research is a methodological framework for the design of innovations in science education. Next, we advance with the theoretical foundations that guide the didactic structure, that is: (i) model-based science teaching and place-based learning; (ii) the use of immersive technologies to help students transit and transition between models and scales; (iii) misconceptions of snails in science education; (iv) fieldwork and characterization of the species under study; (v) curricular mapping to place the resource in the school context. Next, we present the decisions in the design of the learning activities that support the sequence, that is: (vi) the progress matrix with the tasks and type of actions performed by the students; (vii) the design and programming elements of an Android Application Package (APK) that will activate the augmented reality and artificial intelligence resource, allowing access to those aspects of

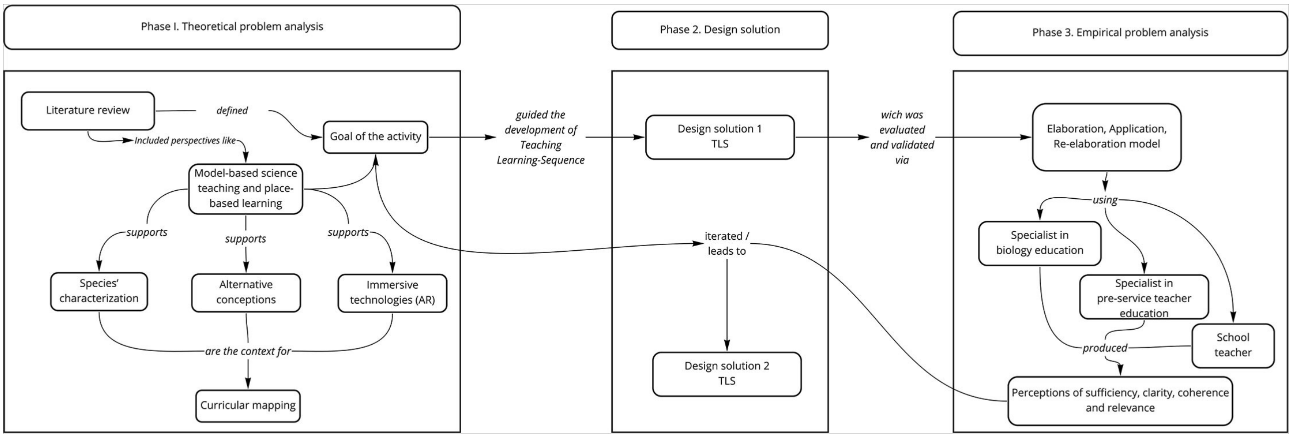


FIGURE 1 | DBR structure followed for the elaboration of the TLS (Adapted from Pernaa et al., 2022).

snails, their habitat and specific interactions that are otherwise inaccessible. We continue with validation, where (viii) the results of the expert peer review process and the use of statistics, such as the Kappa index, are presented to reduce the subjectivity of the observers. Finally, we close with the changes made to the TLS in the re-elaboration stage, which allowed us to (ix) make adjustments regarding the instructions and type of demand in the development of activities and tasks. For ample reasons and timeframe of the article, the process of implementation, iteration, and upcoming results will be published in a second article.

MATERIALS AND METHODS

This methodology is based on teaching-learning sequences' design-based research, which aims to generate knowledge about the nature and conditions of teaching and learning by means of the design and development of educational innovation in the classroom environment. Design-based research (DBR) includes the design, implementation, and assessment of a TLS, which generates new didactical knowledge that can be applied back to the educational system (Barab and Squire, 2004; Kortland and Klaassen, 2010; Guisasola et al., 2021).

Most scholars agree that a DBR project must be developed through design cycles, implementation, analysis, and redesign (McKenney and Reeves, 2018). This methodology does not require any specific educational theory to sustain it or specific tools for any phase, which gives educational researchers freedom to implement a DBR approach (Easterday et al., 2014). In our work for the TLS design, we outline three phases: (a) theoretical problem analysis; (b) design solution (**Supplementary Material 1**); and (c) empirical problem analysis.

The theoretical problem analysis phase includes the characterization of the studied species, their location, and presence in the national school curricula, and associated research in science education. In the design solution phase, the strategies and didactical structures are supported by the curricular map and the learning activities. The empirical problem analysis phase by expert peers revises the activities' coherence, sufficiency, and pertinence, as well as the instrument to analyze the students' tentative answers. Finally, revision and redesign of activities will occur based on implementation experiences. We share our preliminary findings preceding future implementation cycles. In **Figure 1**, we present the DBR structure followed for the elaboration of the TLS (Pernaa et al., 2022).

RESULTS

The results will be presented in three phases as follows: (I) theoretical problem analysis, where we pose the instructional theory behind the design, as well as the findings according to the fieldwork done in southern Chile (northern Patagonia) regarding different snail species, and the curricular mapping as a strategy that leads to the second section, i.e., (II) design solution, where the result is the TLS and the educational resources that enhance it with AR; and (III) empirical problem analysis, where we present how the TLS was validated, and also the feedback we received from evaluators, leading to certain aspects of redesign.

These findings allow the development of a TLS with AR resources centered on snails as a paradigmatic fact to enhance biodiversity's comprehension through interdisciplinary work.

Phase I. Theoretical Problem Analysis

Learning Science Based on Models to Promote Visualization Through Immersive Technologies

To understand how a snail works is not simple; it requires knowledge of how internal structures function and how organs are organized inside the shell. This also invites wonder about how the shell forms, leading to many interesting questions whose predictions, explanations, and argumentations are sustained in a model (Hernández et al., 2015). Choosing this model-based approach utilizes authentic scientific practices in the context of the application of our Sequence, as well as linking natural phenomena with models to construct and reconstruct the theoretical concepts for students.

TABLE 1 | Instrument to analyze students' answers to the proposed activities of the TLS.

Code	Levels	Description
L1	Level 1—Representations as description	When they are asked to represent a physical phenomena, students generate representations based only on their physical characteristics. This means that the representation is an isomorph, an iconic description of the snail in a particular point in time.
L2	Level 2—Rudimentary symbolic capacities	Students are familiarized with a formal representation system, however its use is only a literal reading of the representations' surface characteristics' without taking into account syntax and semantics.
L3	Level 3—Sintactic use of formal representations	Students are able to make connections between two different representations of the same phenomenon based only in the syntactic rules or common shared superficial characteristics, rather than the subjacent meaning of the different representations and their shared characteristics.
L4	Level 4—Semantic use of formal representations	Students are able to bring an underlying common meaning to several types of representations superficially different and transform any other given representation into an equivalent representation about snails and their environment. Students use representations in a spontaneous way to explain a phenomena, solve a problem, or to make a prediction about gastropods life.
L5	Level 5—Reflexive use	Students can use the specific characteristics of a representation to justify the problems inside a social and rhetorical context. They can select or build the most adequate representation to a particular situation and explain why the representation is more appropriate than others to give accounts of the life and ecosystem where the snails live.

To date, it is known that the design, development, use, and construction of models support visualization. This capability includes the "internal" (mental) and "external" (public) representations. The ways of external representation are of special interest and particular relevance in science education, including concrete, gestural, visual-static (graphics, images, diagrams, and equations), visual dynamic (animation, simulation), auditive, and oral (Gilbert, 2008). The capacity to "move" through these representations allows the central element of modelization to happen: the design and execution of experiments associated with scientific thinking. In this line of work, snails are excellent models that can raise many questions about what is inside their shells, entailing diverse representations.

Therefore, if we want to support our students in developing these representations, we need resources that help construct disciplinary knowledge and implement appropriate symbolic systems, so that students can interpret it through visual language. Reading images to extract relevant information about phenomena is a completely different competence from the interpretation of written school texts, and that way an alternative strategy would be developed for teaching or learning scientific phenomena (Savinainen et al., 2013).

In specialized literature, it is possible to find studies in science that use immersive technologies, such as augmented reality to strengthen formative processes, especially with complex phenomena (Küçük et al., 2016; Moro et al., 2017). Additionally, the Horizon Report (Brown et al., 2020) describes augmented reality as a technology that will have a significant impact on education in the next 5 years (2019–2023), and would have a higher potential for the training of citizens and professionals that the digital societies need. Personalization for promoting inclusive learning using AR is also a growing area of interest (Bacca et al., 2014). Therefore, we resort to this technology, as it combines real-world objects (snails) with virtual objects that seem to coexist in the same space as in the real world (Azuma et al., 2001). With AR, students will benefit from the relationship between objects in the space that surrounds them with the concepts learned and acquire skills to interpret knowledge with experiences and experimentation in the real world (Fabri et al., 2008). For example, students will be able to explore the interior of the snail (internal structures) and processes linked to its habitat, such as environmental resources, size, kinetics, distance, or others, which are is not possible to access through conventional educational methods (Ibáñez and Delgado-Kloos, 2018).

In our case, we are interested in the relation between the resources' use and the assessment of possible changes or developments in students' capabilities of visualizing the studied phenomena, in this case, the interior of a snail. To solve this, we find, in Kozma and Russell's (2005) proposal, a hierarchical organization based upon levels of representation and visualization in science (**Table 1**), which we have adopted in our study. Other studies have also adopted this proposal, elaborating rubrics and protocols (González et al., 2020), and for this, we consider this option to revise the students' productions that arise from the sequence's implementation in the classroom, presented in the **Supplementary Information**.

For the operationalization of these variables, students' productions would be revised and classified according to the levels as described in **Table 1**. This way, variable [M] is the total number of students; and as per Kozma-Rusell's level, they are represented as variable [N]. We hope to find levels from N1 to N5, considering Level 1 (L1) as the simplest means of representation and Level 5 (L5) as the most complex level of representation.

Finally, we have also considered the Place-Based Education (PBE) approach to enrich this sequence's design, given that this brings students the opportunity to collect data in their localized context (Clark et al., 2015). Also, using local contexts, students engage in real-life hands-on activities, strengthening their bonds with the community (Murphy, 2020). In this sense, PBE aims to overcome the division between the classroom and community, producing opportunities where students participate and are part of actions and territorial decisions (Smith, 2013), opening spaces to favor connections between the people who inhabit the territories (Gruenewald, 2003) and local suitability of the curricula (Oliver, 2007).

Alternative Conceptions of Snails in Science Education

The explanations that students gave about snails were considered relevant for the resources' design. Different researchers approach snails as a species of interest in science class from the first years of school. For example, Cerda Lorca and and Villarroel Del (2008) present an innovation for science classes from preschool until 6th grade to engage students in inquiry activities that are mediated with snails as living organisms. In another instance, Rybska et al. (2014) found in a classroom experience with a live snail, the drawing of snails' internal structure, that schoolchildren generally anthropomorphize other animals. Rybska et al. (2014) also explores the relevance of snails as objects of study for scientific inquiry experiences, illuminating the didactical value of the snail, and its biological importance as an organism in an ecosystem. Snails have also been studied to develop modeling competence in the context of teaching and learning evolution (van Joolingen et al., 2019) mediated by drawings, using computational support that enables students to translate the language of the drawing to a model. These research experiences in science education support the use of snails as a versatile object of study for science class. Additionally, snails can serve as a vehicle for combining science and science education research. Next, we present characterization data and the information gathered in the field.

Species' Characterization

Aside from the educational components of this work, the scientific goal of this study was to describe the geographical distribution and morphological variation of Chilean malacofauna. We initiated this work in January 2022 by conducting an exploratory survey of land snails and slugs in the southern part of Chile. During this fieldwork, we found and collected 18 species of gastropods, 10 of which were native, and eight were introduced (see **Figure 1** for distributions).

The species we most commonly found were land snails and slugs that are native to Europe. These included the common garden snail *Cornu aspersum* (Family Helicidae), garlic snail *Oxychilus alliarius* (Oxychilidae), and five species of slugs from three families: *Limax maximus, Deroceras reticulatum*, and *D. invadens* (Limacidae), *Milax gagetes* (Milacidae), and *Arion intermedius* (Arionidae). Additionally, specimens of freshwater *Physella* sp. were found in the Aconcagua River. The direct impacts of these introduced species in Chile are largely unknown, but several of them are known agricultural pests or vectors of parasites in their invaded ranges, and likely pose similar threats in Chile.

However, our research team is particularly interested in exploring biodiversity in native land snails in South America (Parent and Crespi, 2006; Phillips et al., 2020; Kraemer et al., 2021). Globally, snails possess extraordinary diversity and high levels of endemism, and represent 70% of mollusk extinctions. In addition, non-marine mollusks represent 40% of known extinctions since 1,500, and land snails represent a large number of these (Lydeard et al., 2004; Parkyn and Newell, 2013). Snails in Chile are no exception. No native land snails in Chile are assessed using the International Union for Conservation of Nature (IUCN) criteria, despite a potentially underappreciated species diversity across the Andes Mountains (Breure, 1978; Breure and Araujo, 2017; Breure et al., 2022). The native land snails collected during this work represent four different families: Succineidae (*Succinea chiloensis*), Bothriembryontidae (*Plectostylus chilensis, P. peruvianus,* and *P. vagabondiae*), Strophocheilidae (*Chiliborus* sp.), and Charopidae (*Stephanoda binneyana*). Native freshwater *Chilina* snails were also found in the southern part of our survey.

Additionally, although they were not the target of our work, marine shells were found inland in gravel piles specifically: *Incatalla cingulata*, *Acanthina monodon*, *Felicioliva peruviana*, and *Prisogaster niger*. Additional 10 species of marine gastropods were collected during public engagement with elementary-level students: *Acanthina monodon, Austrolittorina araucana, Crepipatella dilatata, Diloma nigerrimum, Fissurella nigra, Nacella magellanica, Scurria scurra, Siphonaria lessonii, Tegula atra*, and *Xanthochorus cassidiformis*. The presence of these 10 species from 10 separate genera collected from a localized region demonstrates the impressive community diversity of Chilean gastropods.

All live specimens we collected were preserved in 95% EtOH and returned to the Parent Lab at the University of Idaho (United States) for future genetic and morphological analyses. Empty shells were also collected when available and were stored in vials for future geometric morphometric analyses. The terrestrial mollusk species we found encompass the breadth of snail species and ecological (including terrestrial, marine, and freshwater habitats) diversity of Chile, which spans over 400 million years of evolution. Considering that most of the continental territory of Chile is cataloged as one of the global biodiversity hotspots (Alaniz et al., 2016), the distribution of the collected snails (**Figure 2**) is relatively wide in a diversity of environments.

In relation to invasive and native species, it can be indicated that they are more homogeneously distributed equally in the collection areas. This could indicate the extensive adaptation of snails to inhabit this diversity of environment, especially terrestrial species, whether invasive or native, which appear as the majority.

Curricular Mapping for Snails' Learning Opportunities

To strengthen students' formation in their knowledge and scientific/technological literacy regarding the role that species, populations and ecosystems play roles in the configuration of biodiversity and its conservation (Tasquier et al., 2022), a better interdisciplinary articulation of the opportunities that curricula offer is required. This operates as a guide and orientation for the educational and teaching decisions that teachers make when they decide on implementing teaching for science learning (Skamp et al., 2013).

It is relevant to use a curricular map that facilitates the search for learning opportunities centered on biodiversity, including snails as an object of scientific knowledge in our example. Curricular maps allow educators to have a graphical representation that organizes, distinguishes, and relates different types of content and learning objectives from one or more disciplines with relevant themes and/or school emerging projects. To elaborate, there are a variety of curricular references that

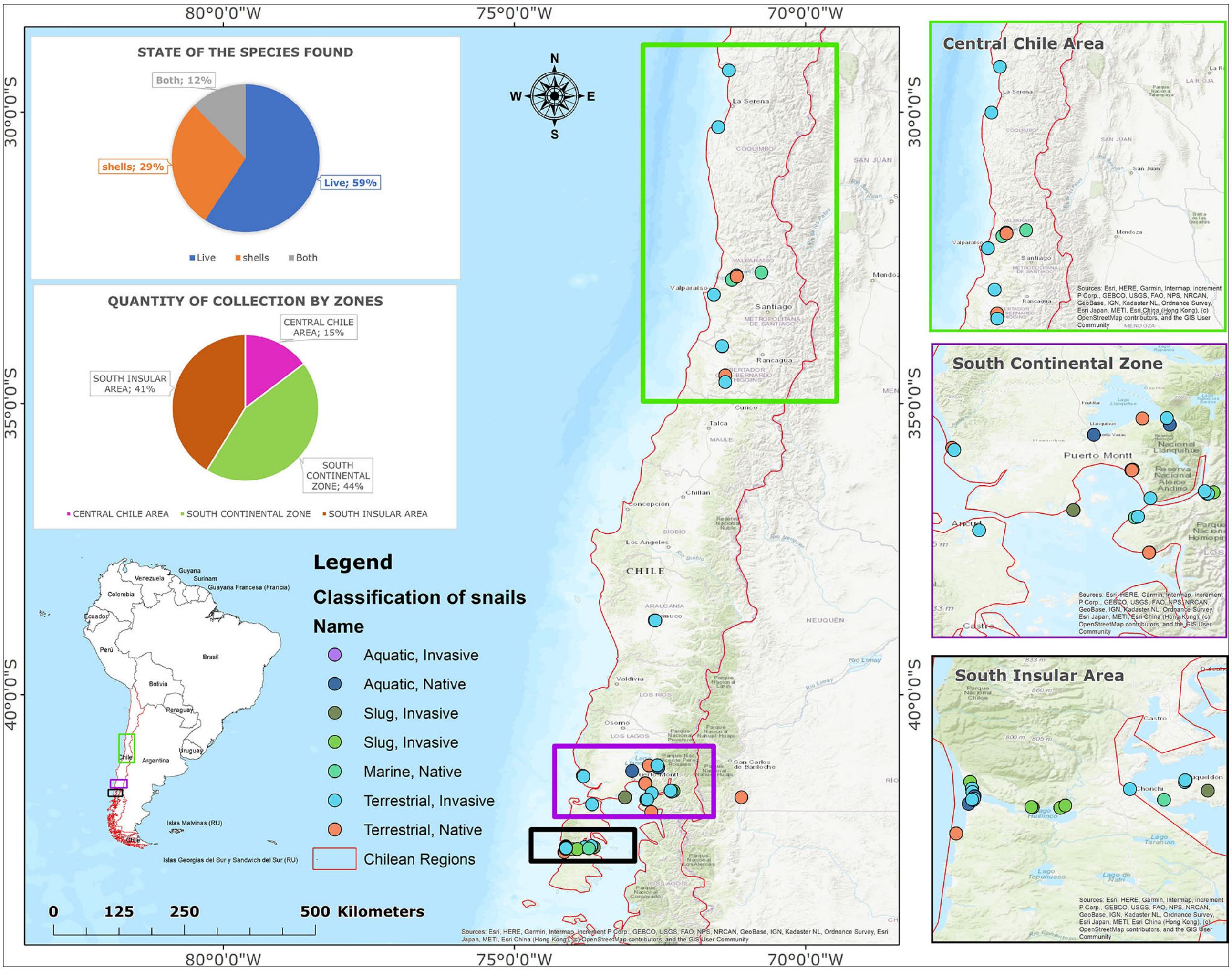


FIGURE 2 | Location of snails collection in Chile (Elaborated by Paulina Ampuero).

are compared and analyzed, teaching perspectives, and high-quality external sources of information (González-Weil et al., 2014). Showing the general structure of these relations allows one to have a general vision of how the elements that compose it get distributed, and the relations among them, as well as with other elements different from the prescribed curriculum, thus granting a more contextual and interdisciplinary approach. In this case, mapping requires considering the mediator potential of the digital technologies, their characteristics for representation, amplification, implication, exemplification, and direct interaction with scientific knowledge's objects (Kozma and Russell, 2005; Savinainen et al., 2013).

Our curricular mapping searches opportunities for learning about snails' role in the configuration of ecosystems and their biodiversity through the relationship between the Learning Objectives (LO) of the Science, Technology, and History, Geography, and Social Science subjects, present in the Chilean National Curriculum (MINEDUC, 2019). The analysis of the National Curriculum allows us to map 26 Science's LOs to learn about snails as an object of scientific knowledge for ecosystems and their diversity (**Table 2**). The Science LOs operate as anchor objectives and can be connected with 30 History, Geography, and Social Science's Los and/or 45 Technology's LOs. The extent of these LOs and their interdisciplinary relations are summarized in **Table 2**.

In this way, relations emerging between LO that favor interdisciplinary approximations are consistent with a STEM approach, allowing the elaboration of TLS that content technological objects as augmented reality, thus enabling the development of more complex, long-lasting, and contextualized learning. That is, the process of curricular mapping and its resulting maps give a wider, solid, and consistent base to design and execute learning activities in the classroom.

In the first case, it is possible to use an anchor Science LO that allows the inclusion of snails as an object of knowledge, whose learning process can be developed and empowered by adding a LO from the Technology subject. Then, the Science LO 02 for 1st grade, "*Observe and compare animals according to their*

TABLE 2 | Summary of the mapped LOs with connections opportunities.

Class	Science (anchor)	Technology	History, geography and social science
1st grade	CN01-LOs 1, 2, 10, and 12.	TE01 LOs 1, 3, 4, 5, and 6.	HI01 LO 13.
2nd grade	CN02-LOs 2, 4, and 5.	TE02 LOs 1, 3, 4, 5, 6, 7.	HI02 LOs 1, 2, 6, 8, 9, 10, and 11.
3rd grade	CN03-LO 4.	TE03 LOs 1, 3, 5, 6, 7.	HI03 LOs 3, 5, 6, 8, 9, and 12
4th grade	CN04-LOs 3, and 4.	TE04 LOs 3, 4, 5, 6, 7.	HI04 LOs 6, and 8.
5th grade	CN05-LO 1	TE05 LOs 1, 2, 3, 4, 5, 6, and 7.	HI05 LO 13.
6th grade	CN06-LOs 2, 3, and 16.	TE06 LOs 1, 2, 3, 5, 6, and 7.	HGyCS6 LO 13.
8° grade	CN08-LOs 2, 3, 4, and 15.	TE08 LOs 1, 2, 3, 4, and 5.	HGyCS8 LOs 20, and 22.
9th grade	CN1M BIO LO 4.	TE1M LOs 5, and 6.	HI1M LOs 4, 5, and 10.
10th grade	CN2M BIO LOs 6, and 7.	TE2M LOs 5, and 6.	HI2M LOs 6, 24, and 25.
11–12th grade	CPC AS LOs 2, and 3 CPC SPA LO 1	CPC TyS LOs 1, and 3.	HGSC MGlo LOs 3, and 7. HGSC ChLa LOs 5, and 7.

Self elaborated.
The subject's nomenclature is the one used as code in the Chilean National Curriculum (MINEDUC, 2019).

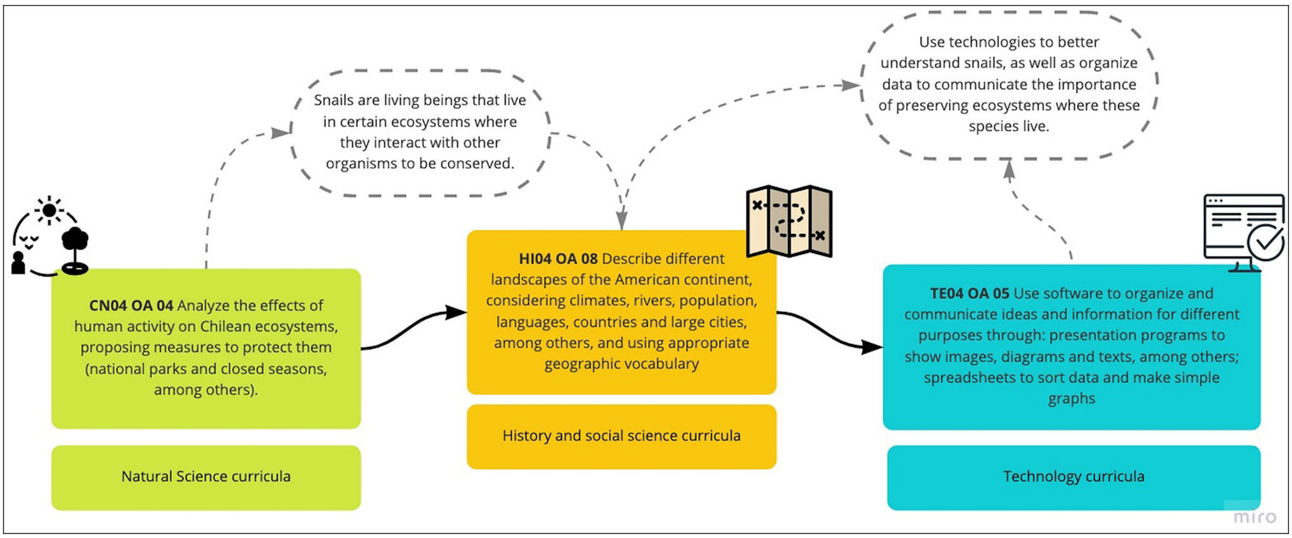


FIGURE 3 | Curricular mapping selected for the elaboration of a TLS mediated by augmented reality.

characteristics, such as size, body cover, displacement structure, and habitat", can be worked along with learning outcomes for Technology's LOs 3 and/or 5, which aim to elaborate technological objects to answer challenger (LO3) and/or the use of software to create and represent ideas (LO5).

In a second case (**Figure 3**), it is observed that an anchor Science LO (e.g., number 3 for 4th grade) "*Analyze the effects of human activities in Chilean ecosystems, proposing measures to protect them (national parks, closed seasons, among others)*" can be developed and empowered by adding LOs from another subject, like History, Geography and Social Science (LOs 6 and 8), and both link up with Technology's learning (LOs 5, 6, and/or 7). This way, eight relations arise that would inspire and grant the TLS's design.

To elaborate on a TLS supported by augmented reality, one relation has been selected from these eight relations that allows the articulation of the effect of human activity on Chilean ecosystems with the descriptions of landscape and their geographical characteristics (LO 8 from History, Geography and Social Science), and these along with software are used to organize and communicate ideas and information with different purposes (Technology's LO 5).

Phase II. Design Solution

From phase I, valuable information has been gathered that converges in **Table 2**. The criteria for designing TLS with immersive technologies will point to: (1) promote the formulation of questions; (2) develop and use models; (3) plan and conduct researches; (4) analyze data; (5) use mathematics and computational thinking; (6) build explanations and design solutions; (7) participate in arguments based on proof; and (8) obtain, evaluate, and communicate information. This points to equipping the population with scientific skills and knowledge related to STEM-integrated approaches where teaching and learning science are considered necessary to train students for a changing socio-environmental and territorial context. In addition, instructional design gathers the principles of scientific practices (López et al., 2017) and STEM (Bybee, 2013), in a form of layers, based on the scientific activity schemes proposed by Osborne (2014), which positions three dimensions interdependent of scientific practices proposed by Duschl and Grandy (2012): modelization (construct theory and models), inquiry (collect and analyze data from observations or experiments), and argumentation (assessment of proofs and constructing arguments). In this way:

1) The first layer visualizes the relationship between the real world and the world of ideas, between phenomenon and its similarity with the model that allows to explain it through a set of statements that are related to data collected from experimentation and/or inquiry (Izquierdo and Adúriz-Bravo, 2021);
2) The second layer gathers the STEM and scientific literacy skills (Bybee, 2013) that can be positioned from inquiry (observe, promote questions, obtain and analyze data, and experiment) or from modelization (developing models, planning researches, using mathematics and computational thinking, constructing explanations, and designing solutions), and the evidence through construction and co-construction of arguments that connects the world of ideas with the real world; and finally
3) The third layer looks for coherence between three cognitive dimensions inherent to any human activity: thinking, language, and action, and levels of the representation of these disciplines: microscopic, symbolic, and macroscopic (Merino and Izquierdo-Aymerich, 2011). This aims for teachers who use the resource to have a straightforward model that allows them to identify and diagnose their students' ways to understand related to the phenomenon surrounding them and can participate, intervene, and make decisions about different interactions in their environment.

Table 3 contains a summary of the activities and tasks present in the TLS. Its progression goes from concrete and simple aspects to more abstract and complex ones (Merino and Sanmartí, 2008). We have tried to include novel aspects, such as: (a) contextualization with the environment and linkage with key actors (teachers from nearby schools, where snails were collected; scientists who investigate the ecology of the snail); (b) curricular articulation between contents and local problems (curricular mapping and interdisciplinary relationships); and finally (c) elaboration of territorially contextualized problems and projects (linked to the environment). The constructed TLS is drawn up in a student's workbook, available in PDF format, and in worksheets in Microsoft Word: https://specto.pucv.cl/ficha-caracoles/. Those resources are complemented with an APK: https://specto.pucv.cl/ficha-caracoles/.

The educational resource comprises a didactic guide for the student and an application for mobile devices with the Android 4.1 operating system. The guide contains images that function as augmented reality marks, linking the printed guide to the app. The first activity is currently available in the application, where the student can point their device's camera at the image of the first mark and see a model of a snail in 3D. You can manipulate this model (rotate, increase or decrease the size, and zoom) and then you can select the option to see the interior of the snail (internal structures). In this case, the model shows the organs inside the snail with their names. The student can enable or disable the option to see the names of the structures. The first version of the APK of this application together with the didactic guide are available at http://specto.pucv.cl.

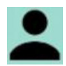
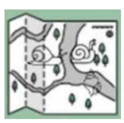
To develop this resource, the Unity 3D was used as the development environment, due to its free characteristics, versatility to package the product for various platforms, amount of existing documentation, and great support for finding solutions. Unity allows the development of the environment, layout, light effects, sound programming, etc. For the incorporation of augmented reality (AR), the Vuforia SDK version 5.0.6 was used. Both software are free as long as the development is not for commercial purposes. Initially, we had selected Metaio as the SDK to develop augmented reality; however, after a short time of work, Metaio ceased to be a free development tool, which forced us to review the available options and stay with the Vuforia. For the development of animated 2D and 3D objects, the Blender version 2.72 software was used. The development of AR applications is well-documented in technical terms, regarding the development methodology, where diverse professionals come together, there is not necessarily enough documentation to be found in this regard.

Another difficulty during development is related to images that are used as trademarks. Since our theme is precisely the visualization capacity, it is of vital importance that each image or icon has a value beyond the simple decoration within a work guide (see **Supplementary Information 1**). In this sense, images used as a brand to activate visual resources became a difficulty, since they had to meet various criteria to be accepted: (a) should be representative and valuable from the point of view of content; (b) should be their own or creative common type to protect copyright; and (c) must have an ideal 5-star rating on the Vuforia SDK. Another difficulty was overcoming those marks whose 3D object load is spatially large, to give an idea of proportionality. This problem was solved using the C# language, since it allows controlling the objects arranged in a Unity scene, changing their size, location, and programming the interaction with the user.

Phase III. Empirical Problem Analysis

Design-based research is a methodological approach that intends to establish a link between educational research and practices developed in school. It is a systematic study of the design, development, and assessment of teacher interventions, and also aims to promote knowledge about the characteristics of these interventions and the processes to design and develop them (Juuti and Lavonen, 2012). Therefore, we accord with the EAR (Elaboration, Application, Re-elaboration) process, developed by Bego et al. (2019), to validate TLSs by following these stages: (1) the elaboration of the sequence in the EAR process has been theoretically based along with its action strategies; (2) the EAR process' application consists of three *a priori* validation stages, carried out according to specific validation instruments

TABLE 3 | A summary of the activities in this sequence.

Activity	Learning cycle's phase	Task	Task type	Goal
A1: What do we know about snails?	1. Express initial ideas	Riddle! 	Individual 	Interest students about snails and their characteristics.
		Black box 	Individual—group 	Make representations based on sensorial experiences and share them.
		Virtual snail 	Group 	Represent initial models using prior representations and information from the app.
A2: Let's go snailin'!	2. Get experimental data	Snailin' in the field 	Group 	Observe and collect field data about snails in the surroundings of the school.
		Snailin' snails 	Individual 	Identify different snails' species and their life cycle using the app.
A3: How is a shell from the inside?	3. Share new points of view	Inside the snail's shell 	Individual 	Visualize with the app the inside of a snail's shell and its parts.
		Modeling a snail 	Group 	Build a snail's model based on the field experience and the place's characteristics.
A4: Are all snails the same?	4. Reach an agreement and build an answer	Snails' map 	Individual—group 	Locate in a map the snails found in the field, describing characteristics of the place.
		Snailed it! 	Group—community 	Communicate their findings about snails in their place through text and drawing.

(validation by specialists, validation by peers, and validation by teachers) and a stage in which the sequence is developed in the classroom, the latter constitutes experimentation in the validation process (not covered in this article). In each of the stages, the sequence can and should be reviewed by the teacher, as a way of validating the sequence. And finally, (3) the redesign: the teacher in possession of the information from the previous phases can confront their perceptions and objectives regarding the elaboration of the sequence. The confrontation of the results represents the closure of the cyclical validation process, when the teacher resumes the elaboration, providing important information and experiences to improve the sequence and his teaching action.

In our case, the TLS was reviewed by: a gastropod ecology specialist; a specialist in biology education; a specialist in training teachers in natural science; and a classroom teacher. They evaluated on a scale of 1–4, sufficiency, clarity, coherence, and relevance of the activities and tasks presented in the

TABLE 4 | Results from the peer assessment process.

	Sufficiency		Clarity		Coherence		Relevance	
Activity	**Mean**	**Cohen's Kappa**	**Mean**	**Cohen's Kappa**	**Mean**	**Cohen's Kappa**	**Mean**	**Cohen's Kappa**
1	3.75	0.85	3.75	0.64	3.75	0.75	4.00	1.00
2	4.00		3.50		3.75		4.00	
3	3.50		3.50		3.75		4.00	
4	4.00		3.25		3.75		4.00	
5	4.00		3.75		3.75		4.00	
6	4.00		3.75		3.75		4.00	
7	4.00		3.75		3.75		4.00	
8	4.00		3.50		3.75		4.00	
9	4.00		3.67		3.67		4.00	

sequence. To determine the level of affinity between the experts' assessments, their differences were evaluated through Cohen's Kappa coefficient (Taber, 2018). The proportion of agreements observed is most important, that is, (a + d)/N. This index is intuitive and easy to interpret; it uses values between 0 (complete disagreement) and 1 (maximum agreement). However, as an indicator of reproducibility, it has the disadvantage that even if two observers were to rank independently, some degree of agreement might occur by chance. The degrees of agreement in sufficiency, clarity, coherence, and relevance of the sequence's activities are presented in **Table 4**. According to Cerda Lorca and and Villarroel Del (2008), a value in the range of (0.61–0.80) is considered substantial.

It can be seen in **Table 4** that the means of evaluators range between the maximum value (four) and one minimum (3.25), showing high levels for each category. Now, a TLS represents the channeling object for the motives and actions of elaborating or re-elaborating a teaching activity. Thus, it is a tool and mediation of the teaching and learning process, in this case, the snail and the ecosystems in which it lives. Another element that permeates the process is research. In phase E (elaboration), the research focuses on each element that makes up the elaboration of the TLS. In phase A (application), the research is in the analysis of a priori validation results obtained through the data built in this application phase. In this process, the investigative approach returns in the R phase (re-elaboration) to the initial objectives, now influenced by the analysis of the results of the first cycle of the process (Bego et al., 2019).

Finally, the validation process allows us to make some adjustments in the activities, based on less agreement between the evaluators. According to the order presented in **Table 4**, we observe that:

- Regarding the category sufficiency, results show that curricular coverage is adequate, and there is a great level of accordance between observers.
- The category clarity addresses how the TLS's order has been expressed and explained to teachers. At this point, we shall make improvements due to less agreement between observers and lower means in the evaluation, especially in tasks 2, 3, 4, and 8.
- In the coherence category, it is necessary to revise several aspects, especially to establish coherence between different activities and tasks. The adjustments will be centered on: (1) reducing the number of tasks in activity 1 and/or complementing it with a song or poetry to raise children's previous ideas; (2) evaluating the work times for children and develop the TLS in at least 3 sessions, especially activity 3 that aims to build a concrete model; (3) promoting the construction of group questions rather than answering individual questions; (4) providing more information in the final activity and instructions on where to find the map of the area and the work scale; (5) increasing the diversity of activities and revising the wording of some instructions for recording data in activity 2.
- Finally, the relevance category shows us how important these activities for 4th grade are for all the evaluators.

DISCUSSION

The central objective of our work was to present a series of criteria and fundamentals that allowed us to design and validate a TLS that incorporates immersive augmented reality technology. To address an interdisciplinary phenomenon and paradigmatic fact, we have created a resource where science, technology, engineering, and mathematics (STEM) converge. To address this problem, we followed a path that involved bridging the divide between scientific inquiry, school scientific inquiry, and the practice of truly multidisciplinary and interdisciplinary STEM education (Martinovic, 2011; Milner-Bolotin, 2018).

The basic didactic structure invites students through the TLS to dialogue with different problems and when solving them, with scientific practices, such as developing models, planning research, using mathematics and computational thinking, constructing explanations, and designing solutions (Bybee, 2013). These practices are key to the development of scientific thinking, especially to explain interdisciplinary phenomena, such as the relationships established between a species and its ecosystem. Place-based learning (PBL) has allowed us to point out local knowledge in the construction of activities, allowing to collect: (a) contextualization with the environment and linkage with key actors and the community (Clark et al., 2015); (b) curricular articulation between contents and local problems (Oliver, 2007), and finally; (c) the elaboration of territorially contextualized problems and projects (Smith, 2013; Iturbe-Sarunic and Merino, 2022).

The experience of collecting and studying the species in the field among scientists, teachers, and schoolchildren provides us with a bridge between scientific and school research. Theoretical modeling processes (Merino and Izquierdo-Aymerich, 2011) are strongly embedded in the area's own knowledge; reasoned and critical thinking based on them cannot be used without any context. It is essential to decide what concrete, cognitive, collective scientific activity, transparently based on data and theoretical principles, will be developed at each educational level (Izquierdo and Adúriz-Bravo, 2021).

Curricular mapping allowed us to identify the relationships between the anchor discipline (Science), History and Geography, and Technology and recognize and identify those spaces of interdisciplinary and multidisciplinary interaction to address the teaching and learning of snails. With this, we show an explicit curricular strategy for the design of STEM activities, where the disciplinary areas that participate in a STEM focus are at the same level of extension and depth, and are not subsidizing one another, as occurs in some proposals where the relationships they are asymmetric and science and mathematics—STEM—predominate (Li et al., 2020).

Although in the literature it is possible to find research on TLS proposals based on production engineering or experimental research (Méheut, 2001), in our case, we stand by DBR given its cyclic structure. Juuti and Lavonen (2012) focus on observing the perturbation that originates an innovation, as it is a TLS with AR, and that perturbation results in theory. In our case, we focus on interdisciplinary teaching and learning about snails with immersive technologies, along with the benefits that promote these kinds of educational resources.

We have discussed perspectives about empirical regulation in the TLS elaboration process (Méheut and Psillos, 2004). This empirical regulation is closely related to the teaching and learning of a species of conservation concern, such as Chilean endemic snails. Even though the validation process with expert peers has been successfully conducted, we still have to verify the validity of the "local" learning hypothesis, within the context of the designed TLS, comparing students' actual cognitive pathways with those anticipated by the design.

CONCLUSION

Our work is an example of how modern educational technologies can help in the process of generating STEM education proposals and in the development of specific skills. However, more evidence-based and on-site research is needed to investigate the impact of these proposals (Milner-Bolotin, 2018), both for students and in the training of teachers to promote their use in immersive technologies, such as augmented reality, so it becomes more accessible for students to visualize their potential in solving problems, and go beyond the motivational effect they can generate.

Future directions of our work involve implementing the TLS and collecting experiences from students for later analysis through the categories established in **Table 1**. Additionally, involving teachers in training through certification and extending activities for more courses in the educational system, as well as non-formal education. Due to all these factors, theories could be expanded with our proposal, and the discussion could be broader, since it would lead us to rethink specific instructional designs, contributing with data on didactic approaches related to modeling, and provide pretext, context, and posttext to real and meaningful problems.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Committee of Bioethics at the Pontificia Universidad Católica de Valparaíso. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CM, CI-S, and BM drafted the manuscript. CP and JP carried out the characterization of the species. AA and JG designed the curricular mapping. SP designed and programmed the Android Application Package with augmented reality. JZ contributed to data analysis. All authors contributed to the design of the teaching–learning sequence. All authors edited and wrote the final version.

FUNDING

This study was supported bt Pontificia Universidad Católica de Valparaíso, Proyecto DI Investigación Innovadora Interdisciplinaria 039.412/2021, Chile and Agencia Nacional de Ciencia y Desarrollo (ANID), Proyecto Fondecyt Regular 1211092, Gobierno de Chile. JGP was supported by research grants from the Systematics Research Fund and the Conchologists of America, as well as a travel grant from the University of Idaho's College of Science. CEP was supported by NSF award 1751157.

ACKNOWLEDGMENTS

Special thanks to the collaboration in the field of: Aldo Macalusso, Director Escuela Río Puelo; Rodrigo Macalusso, Funcionario I. Municipalidad de Cochamó; Luis Corcuera y

Ana Vliegenhart, Fundación Parque Katalapi. https://www.parquekatalapi.cl/; Jessy Hasse, Colegio Mauricio Hitchcock, Contao; Elisa Santander, Escuela Rural Caleta El Manzano; Jordan Paredes y familia, Salto Las Rocas, Estaquilla. https://sites.google.com/view/saltolasrocas; Josué Mallea y Viviana Alarcón, Escuela Rural Estaquilla; Pascal Cartes y Ernesto Fanta, Isla Chaullín/Helvecia, Calbuco; Nelson Mayorga, Cabañas Treng Treng, Chonchi; Rodrigo Ojeda, Alcalde; José Luis Vargas y Diego Maggi, funcionarios, I. Municipalidad Puqueldón; Francisco López, from the Universidad de La Serena, was of great assistance in fieldwork; Paulina Ampuero Paredes, for the layout of the maps and geolocation; Rosario Paredes y Víctor Cáceres, future Science and Math teachers from UACh, for their assistance in the fieldwork; Fernanda Calcina, future Statistician from PUCV, for her assistance in the fieldwork.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.933436/full#supplementary-material

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