



Structural dimensions of a digital learning ecosystem for research skills in secondary education

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ABSTRACT

Despite widespread digital access in secondary education, students continue to demonstrate limited capacity for systematic inquiry, critical source evaluation, and evidence-based reasoning—a paradox that existing virtual learning environments have failed to resolve. This article presents the structural dimensions of a conceptual digital learning ecosystem (DLE) designed to strengthen research skills in secondary education, based on a scoping review of 34 studies published between 2019 and 2025. The findings indicate that inquiry-oriented approaches—particularly project-based learning, problem-based learning, and inquiry-based learning—are the most widely adopted strategies; however, their effectiveness depends on their alignment with structured inquiry processes rather than on the mere presence of digital tools. The reviewed studies also emphasize the role of technological infrastructures, collaborative platforms, learning analytics, and artificial intelligence in supporting school-based research. The proposed DLE model represents a shift from content-centered instruction to structured inquiry environments, enabling students to formulate questions, evaluate evidence, design investigations, and communicate findings. The model integrates human, pedagogical, technological, and support components aligned with five key research phases, contributing to the development of autonomy, critical thinking, and inquiry-oriented learning.

Keywords: research skills, digital learning ecosystem, secondary education, project-based learning, educational technology, inquiry-based learning

INTRODUCTION

The development of research skills in secondary school students is essential to foster critical thinking, autonomy, and problem-solving abilities in increasingly complex educational and social contexts. These skills enable learners to formulate meaningful questions, critically engage with information, apply systematic inquiry processes, and communicate evidence-based conclusions—competencies that are widely recognized as foundational for lifelong learning and informed citizenship. Whilst the importance of research skill development is broadly acknowledged in the educational literature, secondary education remains an underexplored context in this regard, as most theoretical frameworks and pedagogical models have been developed for higher education settings. This gap is significant: secondary school students are at a critical developmental stage in which inquiry dispositions and epistemic habits are being formed, yet they typically lack the self-regulatory capacity, prior academic experience, and institutional support structures available to university students. Addressing research skill development at this level therefore requires purpose-built pedagogical approaches that provide structured scaffolding, progressive challenge, and appropriate ethical guardrails for learners who are still developing their cognitive and academic identities.

The integration of digital technologies in education has opened new opportunities to transform teaching and learning processes by expanding access to information, supporting collaboration, and enabling more flexible and personalized learning experiences. However, the mere availability of digital tools has not translated into meaningful improvements in students' research and inquiry capacities. Traditional virtual

learning environments, such as learning management systems, have primarily functioned as content repositories and administrative platforms, offering access to information whilst doing little to promote the deep cognitive engagement, critical source evaluation, and iterative inquiry processes that characterize genuine research. This limitation reflects a fundamental tension in contemporary education: students today inhabit digitally saturated environments, yet their capacity for systematic, evidence-based inquiry remains underdeveloped—a paradox that cannot be resolved through technology alone but requires a deliberate and theoretically grounded pedagogical framework.

This study is grounded in social constructivism and connectivism as complementary theoretical lenses. From a social constructivist perspective (Vygotsky, 1978), knowledge is constructed through social interaction, guided practice, and the gradual internalization of cognitive tools—a view that underscores the importance of scaffolded inquiry, collaborative learning, and the mediating role of digital tools in supporting research processes. Connectivism (Siemens, 2005), in turn, offers a framework for understanding learning in digital networked environments, where knowledge resides not only within individuals but across interconnected nodes of people, resources, and technologies. Together, these frameworks support the conception of a digital learning ecosystem (DLE) as an adaptive, socio-technical environment in which research skill development emerges from the quality of interactions between learners, educators, digital tools, and information networks—rather than from passive exposure to content.

Within this context, DLEs are conceived as dynamic and interconnected environments in which technologies, users, pedagogical strategies, and data converge to support and enrich learning processes. Previous studies (Nguyen et al., 2023; Punie, 2017; Tammets et al., 2022) indicate that DLEs can support personalized, collaborative, and sustainable learning experiences that place learners at the center of the educational process. Building on this body of research, this article introduces a conceptual model of a DLE aimed at enhancing research skills in secondary education. The proposal is grounded in a scoping review of recent literature, which was conducted to identify key research skills, instructional strategies, and structural dimensions that address the challenges of school-based research in technology-mediated learning environments.

METHODS

This study adopted a scoping review methodology following the framework proposed by Arksey and O'Malley (2005), which includes five stages:

- (1) identification of research questions (RQs),
- (2) identification of relevant studies,
- (3) study selection,
- (4) data charting, and
- (5) collation, summarization, and reporting of results.

Research Questions

The review was guided by the following RQs:

1. **RQ1.** What is the concept of research skills?
2. **RQ2.** What research skills should be developed in secondary education?
3. **RQ3.** What instructional strategies are used to develop research skills?
4. **RQ4.** What is a learning ecosystem and what is its structure?

Search Strategy and Information Sources

The literature search was conducted on Scopus, Web of Science, ERIC, and Dialnet, and was complemented by searches in Google Scholar. Studies published between 2019 and 2025 in English or Spanish were considered.

Table 1. Inclusion and exclusion criteria for research skills articles

Criterion	Inclusion criteria	Exclusion criteria
Title	Include the terms <i>research skills</i> and <i>secondary education</i>	Include the terms <i>research competencies</i> , <i>higher education</i> , <i>postgraduate</i> , or <i>primary education</i>
Document types	Review articles, empirical research articles, case studies, and doctoral theses	Master's and undergraduate theses, research reports, and conference papers
Overall objective	Analyze perceptions, evaluate pedagogical interventions, validate instruments, or design and assess learning environments and instructional strategies aimed at strengthening research skills	Studies whose overall objective focuses on <i>research competencies</i> , <i>higher education</i> , or <i>primary education</i>

Table 2. Inclusion and exclusion criteria for DLE articles

Criterion	Inclusion criteria	Exclusion criteria
Title	Include the terms <i>digital ecosystems</i> or <i>digital learning ecosystems</i>	Studies focused on <i>learning management systems</i> or <i>virtual learning environments</i>
Document types	Review articles, empirical research articles, case studies, and doctoral theses	Master's and undergraduate theses, research reports, and conference papers
Overall objective	Design, investigate, analyze, create, evaluate, or describe proposals related to DLE	Studies whose overall objective is framed within business, administrative, or organizational management contexts

Boolean Search Strings

To ensure transparency and replicability, the exact Boolean search strings used in each database are reported in [Appendix A \(Table A1\)](#). The search strategy was developed through an iterative refinement process, combining controlled vocabulary terms and free-text keywords related to research skills, secondary education, and DLEs.

Two parallel search strategies were applied: one focused on research skills in secondary education and the other on DLEs. Boolean operators (AND, OR), truncation symbols, and phrase searching were adapted to the specific syntax requirements of each database.

Protocol Registration

No protocol was formally registered (e.g., PROSPERO or OSF) prior to conducting this scoping review.

Eligibility Criteria and Study Selection

Relevant studies were selected based on predefined inclusion and exclusion criteria. Two parallel and complementary searches were conducted:

- (a) research skills in secondary education and
- (b) DLEs.

This strategy enabled a structured examination of the study's two core thematic areas.

Screening was performed through title, abstract, and full-text review. The inclusion and exclusion criteria applied in each search are presented in [Table 1](#) and [Table 2](#).

Data Charting

The extracted data were organized according to three analytical dimensions: research skills, instructional strategies, and DLEs. For each study, information regarding reference, overall objective, methodological design, and key findings was systematically recorded.

Quality Assessment

To ensure methodological rigor and strengthen the evidential weight of the studies included in this review, a structured critical appraisal was conducted using validated quality assessment instruments. Given the methodological heterogeneity of the included studies ($n = 34$), different appraisal tools were applied according to the research design. Empirical quantitative and qualitative studies were evaluated using the *mixed methods appraisal tool* (MMAT). Narrative reviews were assessed using the *scale for the assessment of narrative review articles*, whilst systematic reviews were appraised using *AMSTAR 2*. Conceptual and design-oriented studies

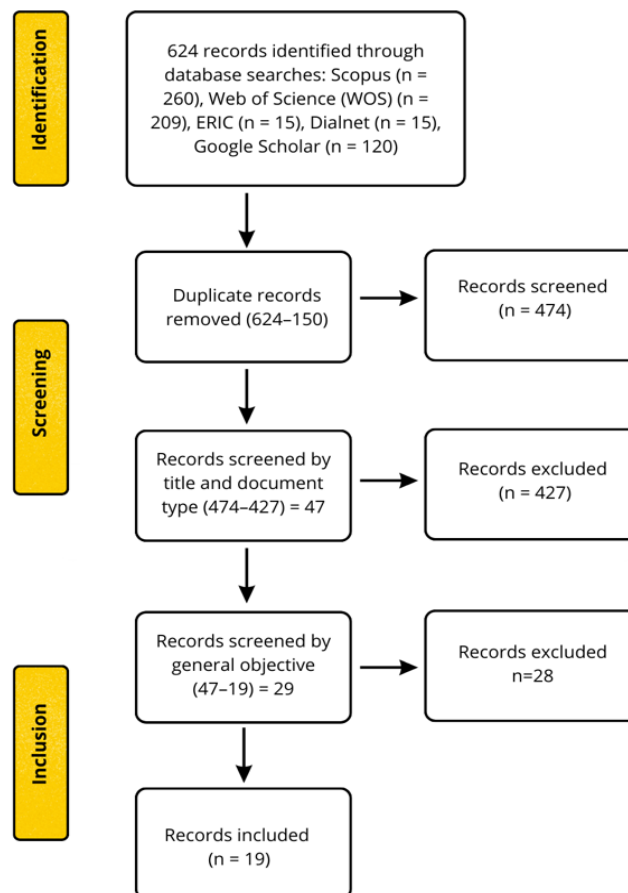


Figure 1. PRISMA flow diagram of the article selection process on research skills (Source: Own elaboration based on PRISMA 2020 guidelines (Page et al., 2021))

were evaluated using the *JBI critical appraisal checklist for text and opinion papers*, and the study employing a design-based research approach was assessed using the quality criteria proposed by McKenney and Reeves (2018). Based on the criteria of the corresponding instruments, each study was classified as high, moderate, or low methodological quality. A detailed presentation of the appraisal process and results is provided in [Appendix A \(Table A2\)](#). Research-related expectations in secondary education are given in [Appendix B \(Table B1\)](#).

Data Synthesis

A descriptive and analytical synthesis was conducted in alignment with the RQs and eligibility criteria. The results are presented through tables and figures to facilitate thematic comparison and integration of findings across the two core domains of the review.

RESULTS

Study Selection

Research skills

The database search identified a total of 624 records across Scopus, Web of Science, ERIC, Dialnet, and Google Scholar. After removing 150 duplicate records, 474 records remained for title and document-type screening. Following this stage, 427 records were excluded, leaving 47 records for full-text eligibility assessment. After evaluating these records against the predefined inclusion criteria, 28 were excluded due to misalignment with the research focus, primarily because they addressed higher education contexts or broader research competencies rather than specific research skills in secondary education.

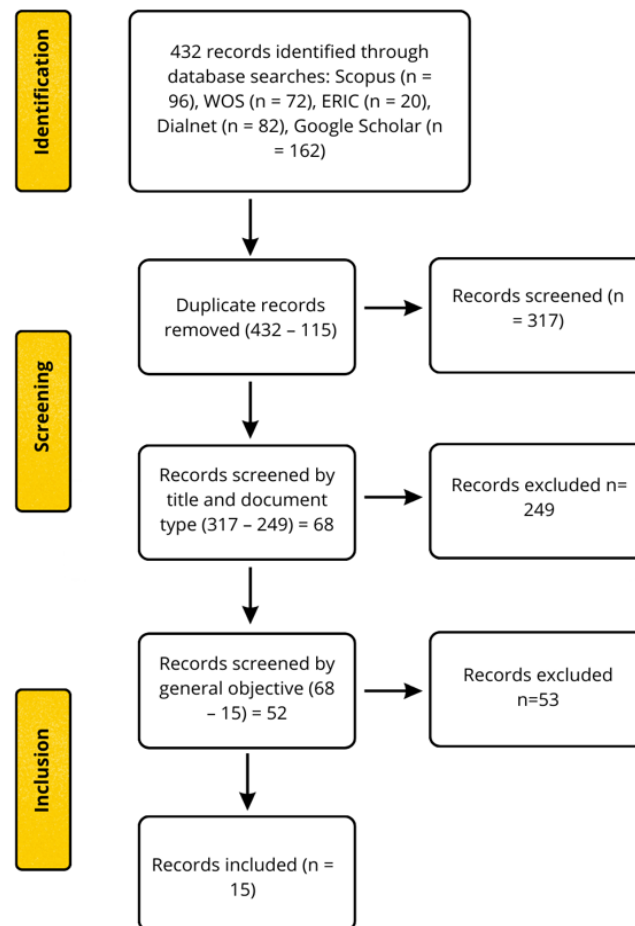


Figure 2. PRISMA flow diagram of the article selection process on DLEs (Source: Own elaboration based on PRISMA 2020 guidelines (Page et al., 2021))

19 studies met the inclusion criteria and were included in the final synthesis. The selection process is summarized in [Figure 1](#).

Digital learning ecosystems

The database search identified a total of 432 records across Scopus, Web of Science, ERIC, Dialnet, and Google Scholar. After removing 115 duplicate records, 317 records remained for title and document-type screening. Following this stage, 249 records were excluded, leaving 68 studies for full-text eligibility assessment. After evaluating these studies against the predefined inclusion criteria, 53 were excluded due to misalignment with the research focus. 15 studies met the inclusion criteria and were incorporated into the final synthesis. The selection process is illustrated in [Figure 2](#).

Thematic Findings

The thematic synthesis of the 34 included studies revealed five major analytical themes aligned with the RQs. These themes reflect conceptual distinctions between research competence and research skills, domains of research skills addressed in secondary education, pedagogical strategies employed to develop such skills, defining characteristics of DLEs, and structural dimensions informing the proposed DLE model. Across the analyzed studies, a convergent pattern emerges in which research skills are consistently conceptualised as stage-based and process-oriented, reinforcing the need for structured and scaffolded inquiry frameworks in secondary education.

Conceptualization of research skills

The analysis of the included studies revealed a persistent conceptual ambiguity between the terms *research competence* and *research skills* within secondary education research. Whilst several studies use both

Table 3. Conceptual distinction between skill and competence in educational literature

Concept	Definition	Main characteristics	Examples
Skill	An acquired capacity to perform a specific task or activity efficiently. It may be cognitive, technical, or social in nature	Developed through practice and repetition. Focused on execution. Does not necessarily imply awareness of contextual application	Interpreting charts, writing reports, solving equations
Competence	An integrated combination of knowledge, skills, attitudes, and values that enables effective performance in specific contexts	Involves knowing what to do, how to do it, and when to apply it appropriately. Context-sensitive and transferable across situations	Communicative competence, research competence, digital competence

Note. Adapted from Zabala and Arnau (2007), Tobón (2006), Organization for Economic Co-operation and Development [OECD] (2005), and Perrenoud (2004)

Table 4. Comparative analysis of research competence and research skill

Concept	Definition	Examples
Research competence	A comprehensive construct integrating knowledge, skills, attitudes, and behaviors required to conduct research effectively within specific contexts	Designing research projects, collecting and analyzing data, interpreting results, and communicating findings appropriately
Research skill	A specific procedural or technical ability applied within particular stages of the research process	Identifying keywords, formulating search equations, stating research questions, coding data, among others

Note. Adapted from Vieno et al. (2022)

constructs interchangeably, a closer examination indicates important conceptual distinctions. A first pattern identified across the corpus concerns the scope of each construct. Research competence is generally framed as a broader, integrative construct encompassing cognitive, methodological, and attitudinal dimensions. In contrast, research skills are more frequently operationalized as specific, observable procedural abilities associated with distinct stages of the inquiry process, such as problem formulation, information searching, data analysis, and the communication of findings. A second pattern relates to operationalization and measurement. Studies focusing on research competence tend to adopt holistic evaluation frameworks, frequently incorporating multidimensional rubrics or global performance indicators. Conversely, research skills are more often assessed through task-based instruments, structured questionnaires, or performance-specific indicators aligned with discrete phases of the research cycle. Additionally, the review shows that empirical interventions in secondary education predominantly target the development of research skills rather than research competence as an integrated construct. This suggests a pragmatic orientation in school-based contexts, where instructional strategies prioritize the strengthening of concrete investigative procedures over the development of broader epistemic dispositions. Overall, the findings indicate that although both terms coexist in the literature, research skills emerge as the more operational and pedagogically actionable construct within secondary education. This distinction provides conceptual clarity for the subsequent thematic analysis and supports the focus of the present review on research skills as the primary unit of analysis. To enhance conceptual clarity, the distinctions identified in the literature were systematized in a comparative framework (see [Table 3](#) and [Table 4](#)).

Research skill domains in secondary education

Table 5 presents the studies that examine the development or assessment of research skills in secondary education in relation to **RQ2**.

Table 5. Research skill domains (RQ2)

Author(s)	Purpose of the study	Study design	Research skills
Alamettälä and Sormunen (2020)	To assess the effect of a pedagogical intervention on the online research skills of lower secondary students	Quantitative non-randomized study	Search planning and query formulation, web search, critical evaluation of information, argumentative use of information obtained online
Bozu et al. (2024)	To explore and analyze the perceptions of upper secondary students regarding their research work	Quantitative non-randomized study	Ability to identify and formulate research problems, design appropriate methodologies, collect and analyze data rigorously, and report results both in writing and orally

Table 5 (Continued).

Author(s)	Purpose of the study	Study design	Research skills
Chávez-Lazarte (2024)	To determine the importance of research skills in public schooling by framing them as a key post-pandemic educational challenge	Qualitative study	Problematization of reality, theoretical conceptualization of the phenomenon under study, empirical verification of reality
Huamani-Anco and Maraza-Quispe (2025)	To evaluate the impact of ChatGPT on the development of research skills in secondary education students	Quantitative randomized controlled trial	Information search, critical analysis, information synthesis, result communication
Junchaya Palomino et al. (2024)	To compare the impact of PjBL and the flipped classroom on research skill development in secondary students	Quantitative non-randomized study	Inquiry case problematization, formulation of innovative problems, inquiry strategy design, data generation and analysis, result evaluation and communication
Lacson and Dejos (2022)	To develop and validate an instrument for assessing research skills at the upper secondary education level	Quantitative descriptive study	Problem identification and conceptualization, information and evidence gathering, research methodology, quantitative analysis, and scientific communication
Maddens et al. (2019)	To develop and evaluate the Leuven research skills test (LRST) for 11 th and 12 th grade students	Quantitative descriptive study	Problem identification, question formulation, hypothesis generation, instrument design, conclusion formulation, and result communication
Maddens et al. (2021)	To design the virtual environment RISSC to promote research skills in upper secondary students in behavioral sciences	Qualitative study	Problem identification, question formulation, hypothesis generation, construction and redesign of devices, evidence generation, evidence evaluation, conclusions drawing, communication and scrutiny
Maddens et al. (2020)	To assess the research skills of upper secondary and first-year university students using the LRST	Quantitative descriptive study	Problem identification, question formulation, hypothesis generation, construction and redesign of devices, evidence generation, evidence evaluation, conclusions drawing, communication and scrutiny
Maddens et al. (2023)	To assess whether a learning environment based on the 4C/ID model enhances students' research skills	Quantitative non-randomized study	Problem identification, question formulation, hypothesis generation, instrument design, conclusion formulation, and result communication
Noriega-Castillo (2022)	To analyze how PBL strategies used by teachers influence the development of research skills in students	Systematic review	Inquiry, source review and analysis, writing and creativity, cooperative and collaborative learning, scientific curiosity, critical and creative thinking, and use of research tools
Rempel et al. (2019)	To verify the skills developed through scientific initiation work by two secondary students in a public school in Lajeado (Brazil)	Qualitative study	Communication, data interpretation, autonomy, scientific writing, fieldwork, critical thinking, technological skills, collaboration
Sagita et al. (2023)	To illuminate the intricate process involved in developing the research skills metacognitive questionnaire	Quantitative descriptive study	Problem clarification, information search, evaluation of evidence, organization of information, analysis and synthesis, and communication and application of results
Salybekova et al. (2021)	To formulate theoretical frameworks and pedagogical methodologies for teaching research skills within biological education, and to implement and assess the effectiveness of PjBL in fostering their development.	Quantitative non-randomized study	Selection of research topic, gathering of scientific information, research methods, research practice, result generalization, presentation of findings

Table 5 (Continued).

Author(s)	Purpose of the study	Study design	Research skills
Santiago and Valtoribio (2022)	To develop and validate a questionnaire to assess fundamental research skills in secondary education	Quantitative descriptive study	Selection of reliable sources, analysis and interpretation of information, application of scientific procedures, oral and written communication of results, research planning, hypothesis formulation, use of statistical procedures
Servado (2024)	To determine research skills in secondary students through self-assessment within IBL	Quantitative non-randomized study	Data analysis and interpretation, use of statistical methods, selection of reliable sources, application of the scientific method, oral and written communication, systematic research planning, hypothesis formulation
Sinensis et al. (2022)	To develop students' research skills through the implementation of the collaborative real-world analysis learning model	Qualitative study	Problem identification, formulation of appropriate objectives, selection of relevant methods, data analysis leading to well-founded conclusions, and the ability to propose contextually applicable recommendations within the research context
Varías-Palacios et al. (2023)	Systematic review of strategies used to develop research skills in secondary education	Systematic review	Source selection, definition of objectives, hypothesis formulation, research planning, result prediction, and hypothesis testing
Yani et al. (2023)	To analyze secondary students' research skills on the topic of plant propagation	Quantitative descriptive study	Observation, question and hypothesis formulation, research planning, data analysis and synthesis, communication of results

A total of eighteen studies were identified as addressing the domains, components, or processes associated with their development among secondary school students. The analysis revealed recurrent clusters that structure how these skills are conceptualised and operationalized across the literature. These clusters were synthesized into five core domains reflecting the main stages of the research process: problem identification and conceptualization, information and evidence gathering, research methodology, data analysis and evidence evaluation, and communication and language.

Table 5 summarizes the authors, study purpose, research design, and the abilities addressed in each study, providing a structured overview of their representation across the selected literature. Further evidence suggests that these domains are not only recurrent across studies but also function as sequentially interdependent phases, indicating that research skill development follows a progressive and cumulative trajectory rather than isolated skill acquisition.

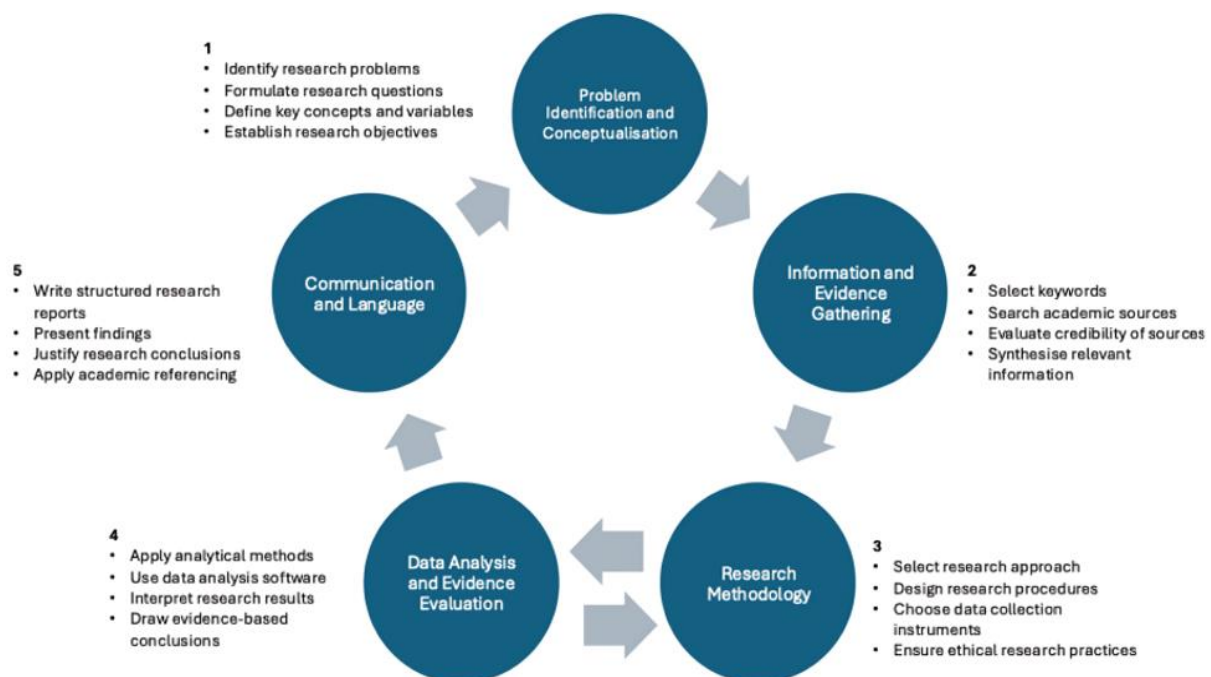
To further contextualize the research skill domains identified in the thematic synthesis, a comparison was conducted with the learning outcomes described in the Colombian national standards for natural sciences education issued by the Ministry of Education. These standards emphasize inquiry-based scientific practices that students are expected to develop throughout secondary education, including questioning, hypothesis formulation, information searching, experimental design, data analysis, and the communication of scientific findings. **Table 6** presents the alignment between the five research skill domains identified in this review and the learning outcomes articulated in the national curriculum framework. This comparison illustrates the consistency between the domains emerging from the analyzed literature and the inquiry-oriented learning outcomes expected in the Colombian educational context (Ministerio de Educación Nacional de Colombia [MEN], 2004).

Figure 3 presents the inquiry cycle that structures the development of research skills in secondary education. The model organizes the research process into five interconnected phases: problem identification and conceptualization, information and evidence gathering, research methodology, data analysis and evidence evaluation, and communication of findings. Each phase integrates specific research skills identified through the thematic synthesis of the reviewed studies. Rather than representing research as a linear procedure, the model conceptualizes inquiry as an iterative and cyclical process, where the communication

Table 6. Alignment between research skill domains identified in the review and learning outcomes from the Colombian national science standards

Research skill domain	Learning outcomes from the Colombian national standards for natural sciences education
Problem identification and conceptualization	Formulating RQs based on observations, developing hypotheses grounded in scientific knowledge and theoretical models, identifying variables that influence experimental results
Information and evidence gathering	Searching for information from multiple sources, selecting relevant information and acknowledging sources, recording observations and results using graphs, tables, and diagrams
Research methodology	Designing investigative procedures, proposing models to predict experimental outcomes, conducting measurements using appropriate instruments and units
Data analysis and evidence evaluation	Analyzing and interpreting data, establishing causal and multicausal relationships between variables, evaluating results considering experimental error
Communication and language	Communicating the inquiry process and research results using scientific language, graphs, tables, and mathematical expressions, relating conclusions to scientific explanations and previous studies

Note. Learning outcomes derived from the Colombian national standards for natural sciences education (MEN, 2004)

**Figure 3.** Inquiry cycle for the development of research skills within a DLE (Source: Authors' own elaboration)

of results may generate new RQs and initiate subsequent cycles of investigation. This visual representation responds to the need to synthesize the identified research skill domains into a coherent process that can guide the design of learning activities and DLE components aimed at strengthening research skills in secondary education.

Instructional strategies for developing research skills

Instructional strategies play a crucial role in supporting the development of research skills, as they create learning environments that encourage students to engage actively in inquiry processes. The analysis of the reviewed studies identified several student-centered approaches that foster critical thinking, collaboration, autonomy, and the integration of digital technologies in school-based research activities. These strategies support different stages of the research process, including problem identification, information searching, methodological design, data analysis, and the communication of findings. The instructional approaches identified in the reviewed literature include project-based learning (PjBL), problem-based learning (PBL), inquiry-based learning (IBL), collaborative learning, discussion and debate, the use of information and communication technologies (ICT), and metacognitive reflection. **Table 7** presents the instructional strategies identified in the reviewed studies and their contribution to the development of research skills.

Table 7. Instructional strategies supporting the development of research skills

Instructional strategy	Purpose
PjBL	Enables the application of research skills in real-life contexts, promoting the resolution of authentic problems
PBL	Supports the development of critical thinking, autonomy, and collaboration among students
IBL	Facilitates the formulation of questions, information searching, and drawing evidence-based conclusions
Case study method	Enhances the ability to analyze real-life situations, identify problems, and propose well-founded solutions
Use of ICT	Provides access to updated information and digital tools for managing and analyzing data
Collaborative learning	Encourages knowledge exchange and skill development in a team-based environment
Discussion and debate	Fosters argumentation, analysis of diverse perspectives, and evidence-based decision-making
Metacognition and reflection	Promotes self-assessment and continuous improvement through critical reflection

The synthesis of the reviewed studies indicates that instructional strategies contribute to the development of research skills in complementary ways. PjBL and IBL were the most frequently identified approaches, as they allow students to engage in the entire research process, from the identification of a research problem to the communication of results. PBL and the case study method strengthen students' ability to analyze complex situations and formulate evidence-based solutions. The integration of ICT facilitates access to information, supports data management and analysis, and enhances the communication of research findings. Finally, collaborative learning and discussion-based activities foster argumentation, reflection, and the exchange of ideas among students, reinforcing the social and dialogical dimensions of the research process.

A notable pattern across the reviewed studies is that the effectiveness of these strategies depends less on the presence of digital tools and more on their integration within structured inquiry processes, reinforcing the central role of pedagogy over technology.

Digital learning ecosystems supporting research skills

The reviewed literature conceptualizes DLEs as complex socio-technical environments integrating technological infrastructures, pedagogical approaches, and social actors that interact to support teaching and learning processes. Across the analyzed studies, DLEs are characterized by the integration of digital platforms, collaborative tools, learning communities, and organizational structures that facilitate flexible, interactive, and data-supported learning environments.

The studies included in this review reveal that DLEs combine technological infrastructures with pedagogical and organizational components that enable collaboration, personalization, and data-informed learning processes. These ecosystems integrate digital platforms, communication tools, learning analytics systems, and networks of actors that collectively support educational innovation and knowledge construction.

Table 8 summarizes the studies addressing DLEs and highlights their main characteristics.

Table 8. Summary of studies on DLEs

Author(s)	Purpose of the study	Study design	Key characteristics of a DLE
Bozkurt and Stracke (2023)	To explore the concept of openness in education and examine how digital transformation influences learning ecosystems and ecologies	Conceptual paper	Open, complex, and adaptive systems composed of interacting with biological and environmental components, systems perspective grounded in ecological systems theory, integration of formal and informal learning, characterization of learning ecologies
Chinchua et al. (2022)	To enhance programming self-efficacy through a problem-based and gamified DLE model	Quantitative descriptive study	Integration of digital learning tools such as videoconferencing, online forums, simulations, and educational games to support interactive and engaging learning environments
Cuong et al. (2023)	To review national and international research on learning ecosystems and smart learning ecosystem markets	Narrative review	Flexible learning agents, adaptive learning content, and innovative learning technologies integrated within creative learning contexts supported by cultural and institutional strategies

Table 8 (Continued).

Author(s)	Purpose of the study	Study design	Key characteristics of a DLE
Hecht and Crowley (2020)	To advocate for the development of a stronger conceptual framework for learning ecosystems	Conceptual paper	Ecosystems composed of diverse actors including students, teachers, parents, community members, and the physical environment, creating supportive contexts that foster learning and development
Lane and Goode (2021)	To design and evaluate an open-source DLE supporting adaptive online learning	Technical conceptual paper	Use of open-source platforms enabling collaboratively created content and open educational resources, continuous ecosystem evolution supported by tools such as blogs, forums, social media, and social bookmarking
Meepung et al. (2021)	To develop an interactive tool within a DLE to support adaptive learning performance	Quantitative descriptive study	Ecosystem characterized by accessibility, identity, interaction, creativity, innovation, responsiveness, and integration, use of digital tools including surveys, questionnaires, gamification, infographics, videos, and live streaming to support formative learning processes
Netto-Silveira et al. (2019)	To develop a conceptual model capturing the complexity and dynamics of learning ecosystems	Conceptual model proposal	Integration of technological components (LMS, websites, databases, authoring tools), pedagogical approaches, social interactions, and organizational structures such as policies and governance
Nugroho et al. (2023)	To design an integrated ecosystem-based learning model for secondary education in Indonesia	Quantitative descriptive study	Technological infrastructure including online platforms, collaborative tools, mobile devices, and connectivity, digital educational resources and communication tools such as forums, video conferencing, and social media, learning management systems and learning analytics supporting student progress monitoring
Pérez-Mallea and Ruiz-Ortiz (2020)	To analyze the evolution of digital learning ecosystems and their future development	Descriptive-conceptual study	Participation of multiple actors including students, teachers, technology developers, content managers, administrators, ecosystem components such as learning platforms, communication tools, repositories, assessment instruments, and learning analytics systems
Pornpongtechavanich and Wannapiroon (2021)	To design an intelligent learning ecosystem platform supporting lifelong digital learning	Technological system design study	Integration of learning factors such as learner characteristics and learning contexts, use of synchronous tools, social networks, mobile learning, online learning, and collaborative learning supported by hardware devices such as computers, tablets, and smartphones
Redmond and Macfadyen (2020)	To propose a comprehensive learning ecosystem framework for managing and optimizing organizational learning	Conceptual framework study	Integration of technology and data architecture, governance structures, learning analytics, semantic e-portfolios, intrinsic and extrinsic motivational factors, social learning processes, and personalization mechanisms
Tammets et al. (2022)	To design a DLE supporting teachers' professional learning.	Design-based research	Adaptive socio-technical ecosystem integrating digital learning tools with user communities including learners, facilitators, and domain experts
Techakosit and Rukngam (2023)	To develop a constructivist instructional model within a DLE to foster self-directed learning skills.	Quantitative descriptive study	Use of digital tools such as videoconferencing, online forums, simulations, and educational games to support both fully online learning and technology-enhanced classroom instruction
Techakosit and Rukngam (2024)	To investigate the effects of constructivist activities in a DLE on academic achievement and self-directed learning skills	Quantitative non-randomized study	Ecosystem composed of biotic components (students, teachers, external experts) and abiotic components including digital tools and technologies supporting both formal and informal learning environments
Tuamsuk et al. (2023)	To identify factors contributing to the transformation of classrooms into learning communities through DLEs in Thai secondary schools	Quantitative descriptive study	Integration of learning platforms, digital tools and resources, collaborative learning communities, data and learning analytics systems, and institutional support and training mechanisms

Table 9. Aspects of the concept of learning ecology

Category	Description
Space	"Space where learning occurs adaptive, dynamic, responsive, chaotic, self-organising, individually driven, living, diverse, with structured and emergent informality" (Siemens, 2005, p. 63).
Contexts	"A set of contexts in physical and virtual spaces that provide opportunities for learning" (Barron, 2006, p. 195).
Processes	Personal learning ecologies are created in environments and social contexts that constitute eco-social systems (Lemke, 2000).
Willingness and capacity	Processes in eco-social systems must be created by individuals with both the will and capacity to do so (Jackson, 2013).
Time	Eco-social processes have temporal and spatial dimensions that connect different spaces and contexts over time (Lemke, 2000).
Systems	Ecologies are living systems with a diversity of factors that interact organically. They are self-organising, adaptable, and fragile (Jackson, 2013).
Networks of possibilities	The environment is conceived as networks of possibilities that extend across time and space, including collective perceptions and cognitions (Barab & Roth, 2006).

Table 10. Self-regulated learning model (Zimmerman & Schunk, 2001)

Phase	Description
Planning	Setting clear goals, selecting appropriate strategies, and conducting an initial assessment of available resources
Execution and monitoring	Implementing strategies, monitoring progress, and adapting in response to obstacles encountered
Self-reflection	Evaluating outcomes, identifying strengths and areas for improvement, and adjusting approaches for future task

Beyond the technological and organizational characteristics identified in the reviewed studies, the literature also emphasizes conceptual perspectives that explain how learning ecosystems operate as dynamic and interconnected learning environments. These perspectives highlight the importance of understanding ecosystems not only as technological infrastructures but also as complex socio-educational systems shaped by interactions between individuals, environments, and learning processes.

Jackson (2013) employs the metaphor of an ecosystem to describe dynamic and systemic interactions applicable to human contexts. Drawing on Germain and Gitterman (1994), he explains that human ecosystems integrate individuals with their physical, social, and virtual environments in continuous processes of interaction, adaptation, and transformation. Within educational contexts, this perspective emphasizes the interconnected nature of learning environments and the multiple contextual factors that influence learning processes. From this perspective, learning ecologies can be understood as networks of interacting spaces, contexts, processes, and actors that collectively create opportunities for learning. Jackson (2013) identifies several key dimensions that characterize these ecosystems, including the environments where learning occurs, the contexts that generate learning opportunities, the processes through which knowledge is constructed, and the networks connecting individuals, resources, and environments. The main aspects of the concept of learning ecology identified in the literature are summarized in [Table 9](#).

Within ecosystem-based learning environments, learner agency becomes a central factor that enables students to actively regulate their learning processes. The literature highlights self-regulated learning as a key mechanism through which learners plan, monitor, and evaluate their actions during inquiry-based activities.

The model proposed by Zimmerman and Schunk (2001) conceptualizes self-regulated learning as a cyclical process composed of three phases: planning, execution and monitoring, and self-reflection. These phases describe how learners organize strategies, monitor their progress, and reflect on outcomes during learning processes. In the context of research-based learning, this framework helps explain how students manage the different stages of inquiry within technology-mediated environments. The phases of self-regulated learning are summarized in [Table 10](#).

Building on these conceptual foundations, the synthesis of the reviewed studies indicates that inquiry-oriented PjBL provides a coherent pedagogical structure for organising learning activities within DLEs. PjBL enables the integration of research stages, complementary instructional strategies, and digital technologies that support the development of research skills.

Table 11. Integration of investigative PBL as the core of the DER

Stage of the pedagogical process	Teacher's and students' actions	Complementary instructional strategies	Digital technologies and AI tools
Problem identification and conceptualization	Identifying a real-life situation, formulating the research question or defining the problem, establishing objectives, project scope, tasks, products, timeline, roles, and evaluation criteria	PBL, discussion and debate, IBL, brainstorming, collaborative learning, project co-design	ChatGPT, Padlet, Miro, Perplexity, Google Docs, Notion AI, Canva Whiteboard, Trello, Genially, Google Calendar, Gamma.app
Information and evidence gathering	Research using reliable sources, use of search tools, information synthesis, construction of theoretical framework, application of ethical citation and referencing standards	Ethical and critical use of ICT, guided reading, source evaluation	Google Scholar, Mendeley, Zotero, Consensus, Perplexity, Diigo, scientific and academic databases
Research methodology	Selection of methodological approach, definition of data collection techniques and tools, study design, data organization, adherence to ethical standards	Guided research workshops, design and methodology debates, field practice, team-based analysis, collaborative analysis	ChatGPT (for survey design), Google Forms, Jamboard, Excel, SPSS, NVivo, ATLAS.ti, MonkeyLearn, Google Sheets + plugins
Data analysis and evidence evaluation	Application of statistical and qualitative methods, interpretation of results, drafting findings, hypothesis validation, formulation of recommendations and conclusions	Guided metacognition and reflection, collaborative writing, peer feedback	Microsoft Word + Copilot, Grammarly, QuillBot, DALL·E for visualizations
Communication and language	Production of final outputs: reports, presentations, infographics, videos, articles, or digital posters	Oral presentation, collaborative learning, instructional material design	Canva, Genially, PowerPoint, Tome.app, OBS Studio, Gamma.app

Within this framework, the digital educational resource (DER) proposed in this study aligns the stages of the research process with instructional actions, complementary strategies, and digital tools that support each phase of inquiry. This integration allows students to engage in authentic research processes whilst interacting with digital resources and collaborative environments. **Table 11** presents the integration of investigative PjBL as the core structure of the DER, illustrating how research stages, instructional actions, complementary strategies, and digital technologies—including artificial intelligence (AI) tools—can be articulated within a DLE.

Building upon the integration of inquiry-oriented PjBL and the technological tools presented in **Table 11**, the conceptual structure of the DLE proposed in this study is synthesized in **Table 12**. This relational framework illustrates how human actors, technological infrastructures, pedagogical practices, and support mechanisms interact within the ecosystem to facilitate the development of research skills in technology-mediated secondary education contexts. Rather than presenting isolated components, the framework emphasizes the dynamic relationships and functional interdependencies among these elements, highlighting the synergy between human participation and digital technologies that sustains IBL processes.

DISCUSSION

Conceptual Distinction Between Research Competence and Research Skill

The results of this scoping review allow for a clear conceptual distinction between *research competence* and *research skill*. Whilst research competence is understood as an integrated set of knowledge, skills, attitudes, and behaviors required to carry out research processes effectively, a research skill refers to a specific technical ability that operates within those processes. This distinction is consistent with the contributions of Vieno et al. (2022) and is particularly relevant for the design of educational proposals that are both precise and sensitive to the developmental and contextual characteristics of secondary education students.

This distinction is particularly significant in secondary education, where students are often in the early stages of developing inquiry abilities. At this educational level, research competence is not yet fully consolidated and therefore needs to be supported through the gradual development of specific research

Table 12. Relational framework of the DLE for developing research skills

Ecosystem dimension	Human components	Technological components	Pedagogical function	Contribution to research skills
Human resources	Teachers, students, tutors, administrative staff	-	Guidance, mentoring, collaborative research work	Development of inquiry, collaboration, and reflection skills
Learning management platform	Teachers and students	Moodle, Google Classroom, Canvas (with AI-supported plugins and assistants)	Content delivery, portfolio management, monitoring progress	Organization of research activities and tracking learning progress
Communication and collaboration tools	Students, teachers, research peers	Microsoft Teams, Zoom, Google Meet, Padlet, Miro and AI-supported collaboration tools	Interaction, co-creation, academic discussion	Collaborative knowledge construction and peer learning
Processes and practices	Teachers and students	AI-supported research assistants (e.g., ChatGPT, Copilot) integrated into inquiry processes	IBL, PjBL, and situated learning	Development of research process skills
Digital learning resources	Students	Scientific articles, videos, simulations, tutorials, academic databases and generative AI tools such as ChatGPT, Perplexity, Gemini or Copilot	Access to materials supporting inquiry activities	Information literacy and conceptual understanding
Data and analytics	Teachers and students	Learning analytics systems, data analysis tools and AI-driven analytics systems	Monitoring participation and providing feedback	Evidence-based improvement of research skills
Mobile devices and ubiquitous access	Students	Smartphones, tablets, laptops with AI-enabled applications	Flexible and continuous access to learning activities	Continuous engagement with research tasks
Network infrastructure and technical support	Technical staff, institutional support teams	Internet infrastructure, system maintenance, cloud services supporting AI tools	Ensuring system stability and accessibility	Sustained functioning of the digital learning ecosystem

skills. Focusing on clearly defined research skills allows educators to design learning activities that guide students step by step through the inquiry process, including problem formulation, information searching, methodological planning, data analysis, and communication of findings. Consequently, distinguishing between competence and skill provides a clearer pedagogical framework for structuring research-based learning experiences in secondary education.

This distinction also highlights the progressive nature of research skill development in secondary education. Rather than emerging simultaneously, research skills tend to develop gradually as students engage in successive stages of the inquiry process. At early stages, learners typically focus on identifying researchable problems and formulating initial questions. As their inquiry progresses, they begin to develop more complex abilities, including information searching, source evaluation, methodological planning, and data interpretation. Finally, more advanced stages involve the communication of findings and the justification of evidence-based conclusions. Understanding research skills as progressively developed abilities allows educators to design structured learning experiences that scaffold students' engagement with inquiry processes and support the gradual consolidation of research competence.

Pedagogical Strategies Supporting the Development of Research Skills

The findings of this review confirm the central role of active, inquiry-oriented pedagogical strategies in fostering research skills among secondary education students. PjBL and PBL emerged as the most frequently adopted approaches across the reviewed studies, a finding consistent with prior research by Noriega-Castillo (2022) and Guo et al. (2020). Both methodologies promote the development of critical thinking, student autonomy, and scientific argumentation by engaging learners in authentic, contextualized tasks that mirror real research processes. Rather than positioning students as passive recipients of information, these approaches place learners in the role of active inquirers who must formulate RQs, gather and evaluate

evidence, design investigative procedures, and communicate findings—processes that collectively engage the full spectrum of research skills identified in this review.

IBL similarly emerged as a significant pedagogical framework, particularly for supporting the earlier stages of the research process, such as question formulation and exploratory information searching. Studies such as those by Salybekova et al. (2021) and Junchaya-Palomino et al. (2024) indicate that structured project-based activities, when appropriately scaffolded, enable secondary students to progressively develop research abilities such as problem identification, methodological planning, data analysis, and communication of findings. Notably, Junchaya-Palomino et al. (2024) found that both PjBL and the flipped classroom model produced significant improvements in research skill development among secondary students, with PjBL showing a slightly stronger association, suggesting that the depth of student engagement with the inquiry process—rather than the mere use of digital tools—is a key factor in skill consolidation.

Collaborative learning strategies also played a complementary role in the reviewed literature. Studies by Sinensis et al. (2022) and Rempel et al. (2019) highlight that working in research teams fosters communication skills, peer feedback, and the co-construction of knowledge, all of which are essential components of the research process at the secondary level. Taken together, the evidence suggests that no single pedagogical strategy is sufficient in isolation; rather, effective development of research skills requires a combination of structured inquiry, collaborative engagement, and sustained metacognitive reflection—conditions that a well-designed DLE is particularly suited to provide.

The Role of Digital Learning Ecosystems in Supporting Inquiry Processes

The reviewed studies consistently highlight the capacity of DLEs to support personalized, collaborative, and student-centered learning experiences. Nguyen et al. (2023), in their study of DLE implementation in Thai secondary schools, identified that the integration of learning support technologies, collaborative platforms, and teaching and learning resources enabled teachers to monitor student progress and adjust their pedagogical decisions accordingly. Similarly, Tammets et al. (2022) demonstrated that DLEs designed around socio-technical principles—integrating digital tools with active user communities—fostered deeper professional engagement and sustained knowledge construction. Although their study focused on teacher learning, the underlying ecosystem logic applies equally to student inquiry processes, where the interplay between technological affordances, peer collaboration, and guided reflection constitutes the conditions for meaningful research skill development. Furthermore, the reviewed literature suggests that the ecological metaphor underpinning the DLE concept—drawing on the notion of biotic and abiotic components in dynamic interaction—offers a productive framework for understanding how different elements of the learning environment contribute to inquiry processes. Studies by Kummanee et al. (2020), Techakosit and Rukngam (2023), and Bozkurt and Stracke (2023) converge in describing DLEs as open, adaptive systems in which learners, teachers, digital tools, and institutional conditions co-evolve. Within such environments, the development of research skills is not conceived as a linear progression through discrete tasks, but rather as an emergent process shaped by the quality of interactions between ecosystem components—a perspective that reinforces the conceptual foundations of the model proposed in this study.

Contribution of the Proposed Conceptual Model

The structural dimensions of the DLE proposed in this study represent a conceptual contribution to the field of technology-enhanced inquiry learning in secondary education. Unlike previous DLE models primarily developed for higher education or professional learning contexts (Redmond & Macfadyen, 2020; Tammets et al., 2022), the model presented here is explicitly designed to address the developmental characteristics and pedagogical needs of secondary school students engaged in school-based research processes. By articulating human, pedagogical, technological, and support components as interdependent dimensions of a unified ecosystem, the model provides a navigable structure that moves beyond the fragmented integration of digital tools that characterizes many technology-enhanced learning initiatives. A distinctive feature of the proposed model is its alignment with the five stages of the school-based research process—problem identification and conceptualization, information and evidence gathering, research methodology, data analysis and evidence evaluation, and communication of findings. This stage-based alignment ensures that the digital tools, pedagogical strategies, and support mechanisms integrated within the ecosystem respond to the specific

cognitive and procedural demands of each research phase. In this respect, the model addresses a gap identified in the reviewed literature, where DLE proposals tend to describe ecosystem components in general terms without establishing explicit connections to the sequential nature of inquiry processes (Pérez-Mallea & Ruiz-Ortiz, 2020). The incorporation of PjBL as the core structuring strategy of the DER within the ecosystem further strengthens the model's pedagogical coherence. By grounding the DER in an inquiry-oriented PjBL framework and complementing it with PBL, IBL, and collaborative strategies, the model ensures that digital tools serve as mediators of meaningful inquiry rather than mere facilitators of information access. The integration of AI tools—including ChatGPT and Perplexity—at specific stages of the research process reflects an awareness of the evolving technological landscape of secondary education, whilst simultaneously positioning these tools within a structured pedagogical framework that mitigates the risks of uncritical or passive use. The model thus offers a coherent and contextually grounded basis for the design and implementation of DERs aimed at strengthening research skills in secondary education.

The Digital Paradox and the Pedagogical Role of Generative Artificial Intelligence

One of the most significant tensions emerging from the reviewed literature concerns what may be termed the digital paradox in contemporary secondary education: whilst students today enjoy unprecedented access to digital technologies and information resources, this broad connectivity has not translated into a corresponding development of research and inquiry skills. Blankendaal-Tran et al. (2025) demonstrate this empirically, showing that pre-university secondary students consistently exhibit significant difficulties in digitally analyzing, transforming, and visualizing data, as well as in conducting systematic information searches and producing research-based writing—challenges that persist despite their routine engagement with digital environments. This paradox suggests that access to technology, in itself, does not foster inquiry; rather, it is the pedagogical framework within which technology is used that determines whether digital tools support or hinder the development of research skills.

The emergence of generative AI tools—most notably ChatGPT and Perplexity—has introduced both new affordances and new challenges for IBL in secondary education and understanding their cognitive and ethical implications requires analytical depth that goes beyond simple enthusiasm or blanket prohibition. From a cognitive load perspective, generative AI tools possess meaningful scaffolding potential at specific stages of the research process. Drawing on load reduction instruction principles grounded in cognitive load theory, Martin et al. (2025) argue that when generative AI tools are integrated in a structured, pedagogically informed manner, they can reduce extraneous cognitive load for novice learners—particularly at the earlier, more demanding stages of inquiry such as problem framing, question formulation, and conceptual organization—thereby freeing working memory resources for higher-order processes such as critical analysis, evidence evaluation, and argumentation. Within this framework, tools like ChatGPT and Perplexity function not as substitutes for thinking, but as cognitive scaffolds that support the gradual internalization of inquiry procedures. However, this cognitive benefit is conditional and context-dependent. Stadler et al. (2024) demonstrate that whilst generative AI reduces immediate mental effort, it simultaneously compromises depth of engagement in scientific inquiry tasks—producing what they term cognitive ease at a cost—with students completing tasks more efficiently but with shallower reasoning and less durable learning outcomes. This tension is further illuminated by research with secondary school students, which shows that without structured guidance, learners tend to use AI chatbots to bypass rather than engage with cognitive challenges, resulting in reduced self-regulation and superficial task completion (Klar, 2025).

The ethical dimensions of integrating generative AI into secondary school inquiry processes constitute a further layer of complexity that demands explicit scholarly attention. Beyond the risks of academic dishonesty and the circulation of hallucinated information, the deployment of AI tools in school-based research contexts raises substantive concerns about algorithmic bias, data privacy, and the erosion of students' epistemic agency. Systematic reviews of AI ethics in primary and secondary education consistently identify that AI systems trained on unrepresentative datasets can reproduce and amplify structural inequalities, producing biased outputs that may disadvantage students from marginalized groups in assessment, content recommendation, and feedback contexts (Gouseti et al., 2024; Wieczorek et al., 2025). Critically, research also reveals that secondary students frequently hold naive or underdeveloped understandings of these ethical dimensions: many do not recognize algorithmic bias as a problem, are unaware of data privacy implications,

and tend to treat AI-generated outputs as objective and authoritative rather than as products of value-laden systems (Gouseti et al., 2024). This epistemic vulnerability—the tendency to accept AI outputs uncritically and to delegate evidential judgement to algorithmic systems—represents perhaps the most fundamental threat that unstructured AI use poses to the development of genuine research competence in secondary education.

Within the proposed DLE model, these cognitive and ethical challenges are addressed through a dual mechanism. First, the model resolves the digital paradox not by restricting access to technology but by embedding digital tools—including generative AI—within a structured pedagogical framework aligned to the five stages of the school-based research process. By linking AI tool use to specific inquiry phases where their cognitive affordances are most appropriate, and by requiring students to critically reflect on AI-generated outputs as part of the formative assessment structure, the model transforms passive digital access into active critical inquiry. Second, the model explicitly addresses AI ethics by positioning generative AI not as an autonomous epistemic authority but as a structured mediator whose outputs must be evaluated, questioned, and contextualized within the broader inquiry process. This approach is consistent with emerging frameworks for responsible AI integration in secondary education, which emphasize that the ethical use of generative AI tools requires not only institutional policy but pedagogical design—specifically, learning environments that cultivate students' capacity to interrogate AI outputs, identify bias and inaccuracy, and maintain epistemic agency in technology-mediated inquiry processes (Gouseti et al., 2024; Wiczorek et al., 2025). Rather than prohibiting or uncritically embracing generative AI, the DLE model thus advocates for a structured, reflective, and ethically informed integration that harnesses the cognitive scaffolding potential of these tools whilst preserving the intellectual rigor and autonomous reasoning that define genuine research processes.

Challenges and Contradictions in Technology-Enhanced Inquiry Learning

Whilst the evidence reviewed in this study points to the considerable potential of DLEs for supporting research skill development in secondary education, a balanced scholarly assessment requires explicit acknowledgement of the challenges, limitations, and contradictions that have been reported in the literature. A critical reading of the reviewed studies reveals that the integration of digital technologies in school-based inquiry contexts does not automatically or uniformly produce improved learning outcomes, and that several structural, institutional, and pedagogical conditions mediate the effectiveness of ecosystem-based approaches.

A recurring challenge identified across multiple studies concerns the digital competence of teachers. Tuamsuk et al. (2023), in their investigation of key success factors for DLE implementation in Thai secondary schools, found that teacher capacity to integrate digital tools meaningfully into pedagogical practices was one of the most significant determinants of ecosystem effectiveness. Where teachers lacked sufficient digital competence or pedagogical flexibility, technology integration tended to remain superficial—reproducing traditional transmission-based instructional patterns within digital formats rather than genuinely transforming the nature of learning. This finding is echoed by Tammets et al. (2022), who observed that even in well-resourced DLE contexts, sustained teacher professional development was essential to ensure that ecosystem components were used in ways that genuinely supported learner agency and deeper engagement with learning tasks. These findings underscore that the effectiveness of a DLE is not a function of its technological sophistication alone, but of the pedagogical vision and professional capacity of the educators who animate it.

A second significant challenge relates to unequal access to technological resources, particularly in low-income, rural, and under-resourced educational contexts. Several studies in the review, including Nugroho et al. (2023) and Chávez-Lazarte (2024), acknowledge that the implementation of integrated digital learning environments presupposes a level of technological infrastructure—reliable internet connectivity, access to devices, and institutional technical support—that remains unavailable to a substantial proportion of secondary schools, particularly in Latin American contexts. This infrastructural inequality means that the benefits of DLE-based inquiry learning risk being concentrated among already privileged student populations, potentially widening existing educational gaps rather than addressing them. The proposed model explicitly incorporates network infrastructure and ubiquitous access as foundational components precisely in recognition of this challenge; however, the conceptual nature of the model means that its practical

implementation must be accompanied by contextually sensitive adaptation strategies that account for varying levels of technological availability.

A third area of tension concerns the risk of technological overload and the superficial integration of digital tools. A recurring observation across the field of technology-enhanced learning is that the proliferation of platforms, applications, and resources within digital learning environments can generate cognitive overload in students, particularly when tools are introduced without sufficient pedagogical scaffolding or coherent integration into the learning process. Rather than supporting focused and progressive research skill development, an excess of poorly coordinated digital tools may fragment students' attention and reduce the depth of their engagement with inquiry tasks. This observation reinforces the importance of the stage-based alignment embedded in the proposed DLE model, which seeks to introduce specific tools at the phases of the research process where their affordances are most pedagogically appropriate, rather than making all tools simultaneously available to learners.

Finally, it is important to acknowledge that some studies in the broader literature on technology-enhanced learning report null or mixed results regarding the impact of digital environments on inquiry skill development. Whilst the studies included in this review were selected based on their relevance to DLEs and research skills, the field as a whole contains evidence of interventions that failed to produce significant learning gains, particularly where implementation was short-term, insufficiently supported, or misaligned with the pedagogical principles of IBL. Acknowledging this complexity does not diminish the contribution of the proposed model; rather, it situates it within an honest scholarly conversation about the conditions under which DLEs can genuinely fulfil their educational potential. The model's effectiveness will ultimately depend on the quality of its implementation, the professional development of the teachers who use it, the technological conditions of the schools in which it is deployed, and the sustained institutional commitment to inquiry-oriented learning as a pedagogical priority.

CONCLUSIONS

This study proposes the structural dimensions of a conceptual model of a DLE aimed at strengthening research skills in secondary education students, developed through a scoping review of recent academic literature. The findings indicate that the development of research skills requires not only active and contextualized teaching strategies, but also integrative and adaptive digital environments capable of supporting inquiry-oriented learning processes.

The proposed dimensions integrate human, technological, pedagogical, and support components, and are grounded in PjBL as the core structuring strategy. In addition, the model incorporates AI tools, collaborative platforms, and formative assessment mechanisms, contributing to the construction of meaningful, autonomous, and self-regulated learning experiences.

It is concluded that the implementation of DLEs represents a viable and innovative alternative for transforming the teaching and learning of research in secondary education. However, further empirical validation of the proposed model is recommended through implementation studies in real school contexts, with particular attention to teacher professional development, technological availability, and the adaptability of the model to diverse educational settings.

To translate these dimensions into practice, a staged implementation roadmap is proposed for school administrators and educational policymakers. In the first phase, institutions should conduct a diagnostic assessment of their current technological infrastructure, teacher digital competence, and existing pedagogical practices related to school-based research. This baseline assessment should inform the prioritization of resources and the identification of institutional capacities that can be leveraged to support ecosystem development. In a second phase, targeted professional development programs should be designed to strengthen teachers' capacity to integrate inquiry-oriented strategies—particularly PjBL and IBL—within digital environments, ensuring that technology serves as a genuine mediator of research processes rather than a supplementary tool. In a third phase, the DER at the core of the ecosystem should be piloted with selected student groups, with systematic monitoring of research skill development through formative assessment mechanisms and learning analytics. Findings from this pilot phase should inform iterative adjustments to the model prior to broader institutional implementation.

Particular attention must be directed towards ensuring the sustainability and equity of DLE implementation in low-resource educational settings. The digital divide—understood as the unequal distribution of access to devices, connectivity, and digital literacy among student populations—represents one of the most significant barriers to the equitable implementation of ecosystem-based learning in secondary education, particularly in Latin American contexts where technological infrastructure remains unevenly distributed across urban and rural schools. Administrators operating in resource-constrained environments are encouraged to adopt a progressive implementation model that prioritizes open-source platforms, low-bandwidth digital resources, and mobile-compatible tools that can function effectively under conditions of limited connectivity. Furthermore, inter-institutional partnerships with universities, public libraries, and technology providers may offer viable pathways for expanding access to digital resources without incurring prohibitive costs. Sustainability, in this context, should be understood not only in technological terms but also as a commitment to the ongoing professional development of teachers, the systematic evaluation of learning outcomes, and the institutional culture of inquiry that must underpin any meaningful ecosystem-based educational initiative.

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APPENDIX A: SUPPLEMENTARY METHODOLOGICAL MATERIALS: SEARCH STRATEGY AND QUALITY APPRAISAL RESULTS

Table A1. Boolean search strings by database

Database	Strategy 1. Research skills (secondary education)	Strategy 2. DLEs	Filters applied
Scopus	TITLE-ABS-KEY(("research skill*") AND ("secondary education" OR "secondary school*" OR "high school*" OR "upper secondary") AND ("project-based learning" OR "inquiry-based learning" OR "educational technolog*"))	TITLE-ABS-KEY(("digital learning ecosystem*" OR "learning ecosystem*") AND ("educational technolog*"))	2019-2025, English or Spanish, article, review
Web of Science	TS=(("research skill*") AND ("secondary education" OR "secondary school*" OR "high school*" OR "upper secondary") AND ("project-based learning" OR "inquiry-based learning" OR "educational technolog*"))	TS=(("digital learning ecosystem*" OR "learning ecosystem*") AND ("educational technolog*"))	2019-2025, English or Spanish
ERIC	("research skill*") AND ("secondary education" OR "secondary school*" OR "high school*" OR "upper secondary") AND ("project-based learning" OR "inquiry-based learning" OR "educational technolog*")	("digital learning ecosystem*" OR "learning ecosystem*") AND ("educational technolog*")	2019-2025, peer-reviewed, English or Spanish
Dialnet	("research skill*") AND ("secondary education" OR "secondary school*" OR "high school*" OR "upper secondary") AND ("project-based learning" OR "inquiry-based learning" OR "educational technolog*")	("digital learning ecosystem*" OR "learning ecosystem*") AND ("educational technolog*")	2019-2025, English or Spanish
Google Scholar	("research skill*" AND "secondary education" AND ("project-based learning" OR "inquiry-based learning" OR "educational technology"))	("digital learning ecosystem" AND "educational technology")	2019-2025, English or Spanish

Note. Search strategies were adapted to the syntax requirements of each database; Strategy 1 was restricted to secondary education contexts, whereas strategy 2 imposed no educational level restrictions; & Searches were limited to publications between 2019 and 2025 in English or Spanish and were conducted between January and July 2025

Table A2. Quality appraisal of included studies (n = 34)

Author(s)	Study design	Appraisal tool	Overall quality level
Alamettälä and Sormunen (2020)	Quantitative non-randomized study	MMAT 2018	Moderate
Bozkurt and Stracke (2023)	Conceptual paper	JBI	High
Bozu et al. (2024)	Quantitative descriptive study	MMAT 2018	Moderate
Chávez-Lazarte (2024)	Qualitative study	MMAT 2018	Low
Chinchua et al. (2022)	Quantitative descriptive study	MMAT 2018	Low
Cuong et al. (2023)	Conceptual paper	SANRA	Moderate
Hecht and Crowley (2020)	Conceptual paper	JBI	High
Huamani-Anco and Maraza-Quispe (2025)	Quantitative randomized controlled trials	MMAT 2018	Moderate
Junchaya Palomino et al. (2024)	Quantitative non-randomized study	MMAT 2018	Moderate
Lacson and Dejos (2022)	Quantitative descriptive study	MMAT 2018	Moderate
Lane and Goode (2021)	Conceptual paper	SANRA	Moderate
Maddens et al. (2019)	Quantitative descriptive study	MMAT 2018	Moderate
Maddens et al. (2021)	Qualitative study	MMAT 2018	High
Maddens et al. (2020)	Quantitative descriptive study	MMAT 2018	Moderate
Maddens et al. (2023)	Quantitative non-randomized study	MMAT 2018	Moderate
Meepung et al. (2021)	Quantitative descriptive study	MMAT 2018	Low
Netto-Silveira et al. (2019)	Conceptual paper	JBI	High
Noriega-Castillo (2022)	Systematic review	AMSTAR 2	Low
Nugroho et al. (2023)	Quantitative descriptive study	MMAT 2018	Low
Pérez-Mallea and Ruiz-Ortiz (2020)	Conceptual paper	JBI	High
Pornpongtechavanich and Wannapiroon (2021)	Conceptual paper	JBI	High
Redmond and Macfadyen (2020)	Conceptual paper	JBI	High
Rempel et al. (2019)	Qualitative study	MMAT 2018	High
Sagita et al. (2023)	Quantitative descriptive study	MMAT 2018	Moderate
Salybekova et al. (2021)	Quantitative non-randomized study	MMAT 2018	Low
Santiago and Valtoribio (2022)	Quantitative descriptive study	MMAT 2018	Moderate
Servado (2024)	Quantitative non-randomized study	MMAT 2018	Moderate
Sinensis et al. (2022)	Quantitative non-randomized study	MMAT 2018	Moderate
Tammets et al. (2022)	Design-based research	DBR quality criteria (McKenney & Reeves)	High
Techakosit and Rukngam (2023)	Quantitative descriptive study	MMAT 2018	Moderate
Techakosit and Rukngam (2024)	Quantitative non-randomized study	MMAT 2018	Moderate
Tuamsuk et al. (2023)	Quantitative descriptive study	MMAT 2018	High
Varías-Palacios et al. (2023)	Systematic review	AMSTAR 2	Low
Yani et al. (2023)	Quantitative descriptive study	MMAT 2018	Low

Note. Of the 34 included studies, ten were classified as high quality, sixteen as moderate quality, and eight as low quality & Empirical studies were primarily appraised using the MMAT, whereas systematic reviews, narrative reviews, and conceptual and design-oriented studies were evaluated using AMSTAR 2, SANRA, and JBI checklists, as appropriate to their methodological design

APPENDIX B: CURRICULUM-BASED RESEARCH-RELATED EXPECTATIONS IN SECONDARY EDUCATION

We summarize curriculum-based research-related expectations that were used as a contextual reference to support the mapping of research skills identified through the literature review. The curriculum framework informed the alignment between research-related expectations and the stages of the school-based research process, without constituting the primary focus of the study.

Table B1. Research-related expectations in secondary education (curriculum-based synthesis)

Research skill domain	Illustrative curriculum-based expectations
Problem identification and conceptualization	Observation of phenomena, formulation of researchable questions, hypothesis generation based on prior knowledge and theoretical models
Information and evidence gathering	Identification of relevant sources, evaluation of information quality, ethical use of information and appropriate attribution
Research methodology	Identification of variables, design of investigative procedures, selection of appropriate instruments and techniques
Data analysis and evidence evaluation	Interpretation of results, use of mathematical and analytical tools, recognition of patterns, relationships, and sources of error
Communication and language	Organization and presentation of results using graphs, tables, and scientific language, formulation of conclusions and generation of new research questions

Note. Adapted from national secondary education curriculum guidelines (MEN, 2004)

