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Developing Student Competency in Exploring the Living World Through Research-Based Teaching: A Case Study

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This study integrates the scientific research method into teaching practices to enhance students' competency in exploring the living world at An Khanh High School in Can Tho City, Vietnam. Guided by constructivist learning theory, which emphasizes active knowledge construction through inquiry-based experiences, this study aligns research-based teaching with competency development. Progress across competency in exploring the living world components (problem identification, hypothesis development, planning, execution, and reporting) was assessed using a pre- and post-test quasi-experimental design. After three months of implementing the intervention (i.e., research-based teaching), this study found that high-performing students consistently outpaced their average-performing peers, benefiting from stronger foundational knowledge and self-directed learning skills. Moreover, the findings highlight that research-based teaching fosters critical thinking, creativity, and practical problem-solving, significantly improving students' analytical and applied skills. This study underscores the transformative potential of active learning approaches in preparing students for science- and technology-driven education.

Keywords: competence development, competency in exploring the living world, pedagogical experiment, research-based teaching

INTRODUCTION

Research-Based Teaching

Research-based teaching (RBT), often aligned with inquiry-based science education (IBSE), has evolved as a transformative pedagogical strategy in science education over

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the past two decades, shifting from teacher-centered transmission of knowledge to student-driven exploration and knowledge construction. This approach involves students actively participating in scientific processes such as formulating questions, designing investigations, collecting and analyzing data, and drawing evidence-based conclusions, mirroring authentic scientific practices (Strat et al., 2024). Rooted in constructivist theories, RBT encourages learners to build understanding through personal experiences and collaborative inquiry, fostering skills essential for the 21st century, including critical thinking, problem-solving, creativity, and scientific literacy (Urdanivia Alarcon et al., 2023). Empirical evidence from systematic reviews highlights RBT's benefits in teacher education programs, where it enhances pre-service teachers' abilities to implement hands-on experiments, leading to improved student engagement and deeper conceptual understanding in natural sciences (Kotsis, 2024). For instance, incorporating practical experiments in RBT boosts knowledge retention and prepares students for advanced scientific research by developing competencies in observation, hypothesis testing, and data interpretation (Cortes et al., 2024). Additionally, RBT promotes lifelong learning by clarifying issues, problems, and questions through structured inquiry, which has increased student motivation and collaborative abilities in diverse educational settings (Seif, 2021). Studies also indicate that while RBT excels in hands-on contexts like project-based learning, it requires careful adaptation to avoid overwhelming low-achieving students or straying from curricular goals (Krajcik et al., 2023; Saavedra et al., 2022). Overall, RBT's efficacy is well-documented in fostering an active learning environment, though its success depends on addressing contextual barriers to maximize benefits for scientific skill development.

Competency in Exploring the Living World

Competency in exploring the living world (CELW) is a multidimensional construct in science education, particularly in biology and ecology, encompassing the skills and knowledge required to investigate and understand living systems, from individual organisms to complex ecosystems. CELW integrates epistemic knowledge (understanding scientific concepts such as biodiversity and ecological interactions), procedural skills (designing experiments, collecting and analyzing data), and conceptual frameworks (connecting biological processes to environmental contexts), enabling students to engage meaningfully with the natural world (Constantinou et al., 2018). Within the framework of RBT, CELW is cultivated through inquiry-driven activities that encourage students to pose questions, conduct hands-on investigations, and draw evidence-based conclusions about biological phenomena, fostering a deeper understanding of the living environment (Pedaste et al., 2015). For instance, students might explore microbial diversity or ecosystem dynamics through structured experiments, applying scientific terms to real-world observations, which aligns with competency-based education models emphasizing constructivist, student-centered learning (Lundeberg, 1990).

Cultivating CELW through RBT is vital for developing global competencies, such as critical thinking, problem-solving, and environmental awareness, essential for addressing contemporary challenges like habitat loss or climate change. Research demonstrates that inquiry-based approaches, closely aligned with RBT, significantly enhance students' abilities to observe, hypothesize, and interpret data in biological contexts, strengthening scientific literacy (Kotsis, 2024; Morris, 2025; Presnillo & Aliazas, 2024). For instance, engaging students in designing experiments to study ecosystem dynamics has improved their ability to connect theoretical concepts with practical applications, promoting attitudes toward sustainable inquiry (Kotsis, 2024; Rashed et al., 2025). Moreover, CELW fosters transversal skills, such as collaboration and evidence-based reasoning, which are crucial for navigating complex socio-ecological issues.

Study Context (An Khanh High School in Can Tho city, Vietnam)

Vietnam's educational landscape has undergone significant reforms over the past decade, particularly through Resolution 29-NQ/TW in 2013, which aimed at comprehensive restructuring to shift from rote memorization to competency-based, student-centered learning, including the integration of research-oriented practices in secondary schools (Ho & Dimmock, 2023). This reform emphasizes learner-centered education (LCE), tracing back nearly five decades, focusing on enhancing critical thinking, problem-solving, and practical skills amid global integration pressures. In secondary education, efforts have included curriculum updates to incorporate social and cultural elements, improved teacher training, and delegation of instructional responsibilities to align with system-wide coherence for learning. However, implementation varies, with higher education leading in student-centered approaches, while secondary schools face barriers like inadequate infrastructure, teacher preparedness, and resistance to change from traditional methods (Ngan et al., 2025). At An Khanh High School in Can Tho City, RBT is being piloted as part of these reforms to develop students' competencies, including CELW, reflecting national goals to transform conventional schooling by replacing grade-based evaluations with feedback systems and eliminating homework in lower levels to foster inquiry. This context highlights Vietnam's push toward ideals-based education in secondary curricula, though local adaptations are needed to address within-school processes and resource constraints (Le et al., 2022). Challenges persist, such as instructional leadership gaps and the need for professional development to effectively implement STEM-oriented reforms, making An Khanh High School a representative case for examining RBT in resource-limited Vietnamese secondary environments (Dimmock et al., 2021). These reforms aim to build a more adaptive education system, but their success depends on overcoming systemic incoherencies and enhancing teacher agency in complex implementation landscapes.

Research Gap, Study Objective, and Research Questions

Despite the established benefits of RBT in fostering scientific competencies, significant gaps remain in understanding its effectiveness within secondary education systems in developing countries, particularly in resource-constrained settings like Vietnam. Substantial literature demonstrates the positive impacts of RBT and inquiry-based learning (IBL) on student outcomes in science education. For example, empirical studies have shown that RBT enhances critical thinking and scientific literacy in secondary biology contexts (Chengere et al., 2025; Kaçar et al., 2021; Urdanivia

Alarcon et al., 2023). Chengere et al (2025) found that guided inquiry-based laboratory activities significantly improved high school students' science process skills in biology, with effect sizes indicating moderate to large gains in procedural competencies. Similarly, Kaçar et al. (2021) conducted a meta-analysis revealing that IBL positively affects academic achievement in science, particularly when aligned with constructivist models. Urdanivia Alarcon et al. (2023) systematically reviewed 51 studies, confirming RBT's role in developing scientific reasoning through hands-on inquiry.

However, most studies have focused on general inquiry-based outcomes in well-resourced environments or higher education, leaving the structured integration of RBT in secondary biology curricula in developing contexts (Cairns, 2019; Chang et al., 2023; Strat et al., 2024). Strat et al. (2024) highlighted gaps in teacher education for IBL implementation, but few empirical evaluations exist for student competency development in biology at the high school level in Vietnam - where educational reforms emphasize competency-based learning, the adoption of RBT in secondary schools is limited by challenges such as inadequate teacher training, limited access to laboratory resources, and entrenched traditional teaching practices (Asian Development Bank, 2020; Mai & Yang, 2013). For instance, studies highlight that inquiry-based approaches, akin to RBT, often face barriers in resource-constrained environments, including insufficient materials for hands-on experiments and varying student readiness for open-ended inquiry (Kotsis, 2024; Moraga-Toledo et al., 2024). Moreover, there is a paucity of empirical research evaluating RBT's impact on specific competencies, such as CELW. This gap is particularly pronounced in Vietnam, where national curricula advocate for student-centered approaches, yet few studies have systematically assessed RBT's role in enhancing ecological and biological understanding among secondary students.

This study aims to assess the effectiveness of integrating RBT into a ten-step teaching process, with RBT embedded at step five, to enhance students' competency in exploring the living world at An Khanh High School. By focusing on a single, well-defined research question, this study seeks to context-specific findings contributing to local educational practices and the global discourse on inquiry-based science education.

The following research questions guided this study:

1. To what extent does the integration of research-based teaching improve students' competency in exploring the living world across its five components (problem identification, hypothesis formulation, planning, execution, and reporting)?
2. How does the effect of research-based teaching on competency in exploring the living world differ between high-performing and average-performing students?

Literature Review

This study was conducted based on *Constructivist learning theory,* which was applied in contemporary studies. This theory posits that learners actively construct knowledge through personal experiences, social interactions, and reflective processes rather than passively absorbing information from teachers. In science education, constructivism emphasizes that students build scientific understanding by engaging with real-world phenomena, testing ideas, and collaborating with peers, which aligns closely with student-centered pedagogies like RBT. This review incorporates the inquiry cycle as a key framework for scientific exploration, as outlined by Pedaste et al (2015), which delineates phases such as orientation (problem identification), conceptualization (hypothesis formation), investigation (experimentation and data collection), conclusion (analysis and interpretation), and discussion (reflection and communication). Constructivism underpins RBT by shifting the focus from teacher-driven instruction to student-driven inquiry, fostering deeper conceptual understanding, critical thinking, and transferable skills essential for scientific literacy (Arega & Hunde, 2025; Strat et al., 2024). Recent systematic reviews highlight how this theoretical foundation supports the development of competencies in dynamic educational environments, particularly in biology, where students must grapple with complex, interconnected systems like ecosystems and biodiversity (Urdanivia Alarcon et al., 2023). The review is organized to first define and scope RBT in science education, then delineate CELW and its measurable components, followed by an examination of empirical studies linking RBT to student outcomes, and finally derive hypotheses to justify the conceptual framework guiding this study.

Defining and Scoping RBT in Science Education

RBT, often used interchangeably with inquiry-based learning (IBL), represents a student-centered pedagogical approach that immerses learners in authentic scientific processes, including questioning phenomena, designing investigations, collecting and analyzing data, and drawing evidence-based conclusions (Pedaste et al., 2015; Strat et al., 2024). At its core, RBT mirrors the practices of professional scientists, encouraging students to explore open-ended questions rather than following prescriptive recipes, which promotes ownership of learning and resilience in problem-solving. Models of RBT vary in their degree of structure to accommodate diverse learner needs and contexts: guided inquiry involves substantial teacher scaffolding, such as providing prompts for hypothesis testing and step-by-step guidance in experimentation, making it suitable for novice learners; in contrast, open inquiry grants greater student autonomy in selecting problems, designing methods, and interpreting results, which is ideal for advanced students to develop independence (Kotsis, 2024; Urdanivia Alarcon et al., 2023). Variants of RBT include the widely adopted 5E model: Engage (to spark interest), Explore (hands-on investigation), Explain (conceptual clarification), Elaborate (application to new contexts), and Evaluate (assessment of understanding) - which integrates seamlessly with STEM education by incorporating technology tools like simulations, virtual labs, or data visualization software to enhance accessibility and engagement (Chang et al., 2023). For instance, the 5E model has been extended in biology classrooms to include digital tools for modeling ecological interactions, allowing students to simulate biodiversity changes without physical resources.

Empirical scoping reveals RBT's versatile application in secondary science education, with intervention durations ranging from short, single-lesson activities focused on specific skills like data analysis to extended semester-long projects that integrate multiple disciplines (Kaçar et al., 2021). In biology specifically, RBT targets real-world phenomena such as ecosystem dynamics, genetic inheritance, or biodiversity conservation, aiming to build procedural skills like observation and inference while connecting abstract concepts to tangible environmental issues (Cairns, 2019; Chengere et al., 2025). A key strength of RBT is its adaptability; however, challenges include teacher training to facilitate open-ended discussions and manage diverse student responses and potential equity issues where students from varied backgrounds may require differentiated support to succeed. In developing contexts like Vietnam, implementation often necessitates adaptation to overcome resource constraints, such as limited laboratory equipment or large class sizes, where traditional rote learning and exam-oriented instruction still predominate (Chau et al., 2024; Ho & Dimmock, 2023).

Defining Competency in Exploring the Living World and Its Measurable Components

The CELW is a multidimensional competency framework in biology education that integrates epistemic knowledge, such as comprehending biodiversity, ecological interactions, and evolutionary processes, with procedural skills like conducting experiments and observational studies, and conceptual applications to understand and address real-world living systems (Constantinou et al., 2018; Pedaste et al., 2015). This competency extends beyond rote memorization to emphasize holistic understanding, where students learn to view the living world as interconnected networks influenced by environmental, genetic, and human factors. Measurable components of CELW, derived from inquiry-based frameworks, include: (1) problem identification and questioning, which involves recognizing biological issues (habitat degradation) and formulating investigable questions; (2) hypothesis formulation and analysis, requiring logical predictions based on prior knowledge and evidence; (3) experiment design and planning, encompassing the creation of feasible methods, selection of variables, and ethical considerations; (4) data execution and analysis, involving accurate collection, statistical interpretation, and error evaluation; and (5) reporting and communication, which entails synthesizing findings into coherent narratives, such as reports or presentations, to share insights and propose solutions (Kotsis, 2024). These components align with broader competency-based education paradigms, such as those in the Next Generation Science Standards (NGSS) or Vision and Change in Undergraduate Biology, which stress transferable skills for tackling global environmental challenges like climate change and biodiversity loss (Morris, 2025; Rashed et al., 2025).

In the context of Vietnamese secondary biology education, CELW directly supports national educational reforms initiated by Resolution 29-NQ/TW (2013), which advocate for a shift from knowledge transmission to competency development, including inquiry skills to foster environmental awareness and sustainable practices (Le et al., 2022; Ngan et al., 2025). Assessments of CELW typically employ rubrics with behavioral indicators on 4-point scales, tracking progression from teacher-guided performance (basic observation with prompts) to independent application (self-directed ecosystem analysis), ensuring reliability and validity in measuring growth (Presnillo & Aliazas, 2024; Thuan & Son, 2025). For instance, rubrics might evaluate a student's ability to link hypothesis testing to real-world biodiversity data, providing formative feedback to guide improvement. This approach measures cognitive gains and attitudinal shifts toward scientific curiosity and ethical responsibility in exploring living systems.

Empirical Studies Linking RBT to Student Outcomes and CELW

Empirical evidence consistently demonstrates that RBT enhances science competencies, including those akin to CELW, with systematic reviews and meta-analyses reporting moderate to significant effects on critical thinking, problem-solving, scientific literacy, and attitudes toward science (Kaçar et al., 2021; Strat et al., 2024; Urdanivia Alarcon et al., 2023). For instance, Kaçar et al. (2021) conducted a meta-analysis of 32 studies, revealing that IBL significantly boosts academic achievement in secondary science (effect size = 0.72), with particularly strong results in biology when hands-on experiments are incorporated to simulate living processes like cellular respiration or ecological succession. Urdanivia Alarcon et al. (2023) reviewed 51 articles, illustrating how RBT strengthens scientific reasoning through constructivist models, with 36 studies emphasizing earth science and environmental topics directly relevant to CELW, such as understanding microbial ecosystems.

In biology-specific contexts, Chengere et al. (2025) employed guided inquiry labs in high school settings to enhance students' process skills, including hypothesizing and data analysis, resulting in significant pre-post gains ($p < 0.05$) in competencies mirroring CELW components, such as improved accuracy in experimental planning and interpretation of biological data. Chang et al (2023) demonstrated that mobile-enhanced inquiry boosts autonomous thinking and procedural elements of CELW, with students showing 20-30% improvements in data execution tasks related to genetic simulations. Cairns (2020) linked open inquiry to metacognitive skills in biology, where students reflected on inquiry processes to better understand complex topics like evolution.

In developing countries, including Vietnam, RBT exhibits promise despite limited widespread application due to infrastructural challenges. Chau et al. (2024) applied the 5E model in middle school natural sciences, yielding significant improvements in problem-solving competencies (effect size = 0.65), directly supporting CELW's planning and execution components through activities like water cycle investigations. Thuan and Son (2025) documented enhanced scientific competencies via IBL in Vietnamese middle schools, with students achieving higher scores in hypothesis testing and reporting when exploring topics like plant biology, aligning closely with CELW. However, variations in outcomes are noted; for example, effects may differ by prior knowledge, with high-performing students gaining more from open inquiry due to their ability to handle ambiguity, while average performers benefit from guided structures (Rivero & Lewis, 2020).

Theoretical constructs like constructivism explain these linkages: learners actively build knowledge through iterative inquiry cycles, resulting in deeper CELW by connecting personal experiences to scientific concepts (Morris, 2025). This process not only enhances cognitive skills but also fosters motivational aspects, such as interest in biology, as evidenced in studies where inquiry boosts engagement in exploring living systems (Tete & Sunday, 2023)

Derived Hypotheses

Based on this review, we hypothesize:

– H1: Research-based teaching integration will significantly improve competency in exploring the living world across all components, as supported by empirical gains in inquiry skills.
– H2: Improvements will be greater for high-performing students due to stronger prior knowledge moderating research-based teaching effects.

This literature justifies the conceptual framework by establishing causal pathways from RBT to CELW outcomes, informed by constructivist principles and empirical evidence.

Conceptual Framework

The conceptual framework models the causal relationship between RBT and CELW in a testable manner, grounded in constructivist theory and empirical evidence. RBT (independent variable: inquiry methods, instructional strategies, teacher guidance, student engagement) is hypothesized to affect CELW. Expected direction: RBT fosters active knowledge construction, improving CELW scores over time (H1), as inquiry cycles enhance procedural and epistemic skills (Pedaste et al., 2015; Urdanivia Alarcon et al., 2023).

Prior knowledge (grouping factor: high-performing students and average-performing students) is hypothesized as a moderator, amplifying RBT's effects for high-performers due to better foundational skills for autonomous inquiry (H2; justified by Cairns, 2020; Kaçar et al., 2021). No mediation analyses were conducted, so other factors are not modeled as intermediaries but noted as contextual influences.

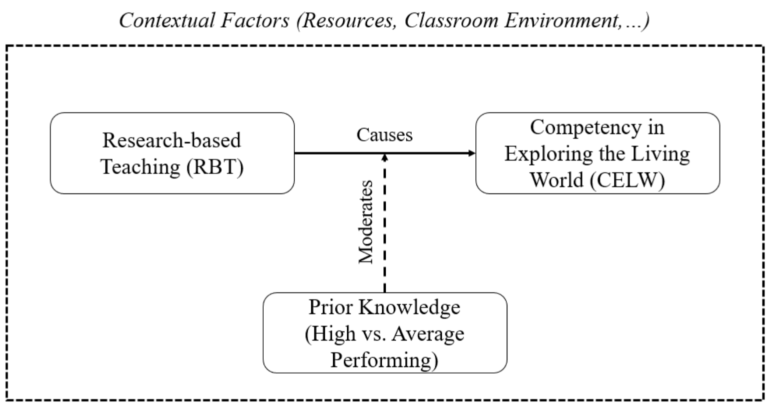

Figure 1
Conceptual framework

METHOD

Research Design

This study adopted a *nonequivalent groups pretest–posttest quasi-experimental design* to examine the impact of RBT on students' CELW at An Khanh High School, Can Tho City, Vietnam. Two intact groups were involved: high-performing and average-performing students, identified from a standardized biology test. Random assignment was not feasible due to ethical and logistical constraints, but pretests were used to control for baseline differences. This design, widely applied in science education research, allows the evaluation of pedagogical interventions in authentic classroom settings (Johnson & Christensen, 2024).

Participants

Participants were 20 10th-grade students from An Khanh High School, selected based on their performance on a standardized achievement test in biology administered at the start of the academic year. Students scoring in the top 30% were classified as high-performing (n = 10), while those in the middle 40% were classified as average-performing (n = 10). This purposive sampling used intact groups from existing classes to minimize disruption, reflecting common practices in school-based quasi-experimental research (Johnson & Christensen, 2024). No random assignment was employed, as students remained in their natural groupings to preserve ecological validity.

The small sample size (n = 20 total) was influenced by practical constraints inherent to the study's context. Limited resources, including a single classroom setting and restricted access to additional participants due to school scheduling and ethical considerations, restricted the ability to recruit a larger cohort. This reflects the challenges of conducting pilot research in a resource-constrained environment like An Khanh High School, where expanding the sample would require significant adjustments beyond the study's scope.

The small sample size was justified by logistical constraints in a single-school pilot study and aligns with similar quasi-experimental investigations in pedagogy that have successfully employed modest participant numbers to yield meaningful quantitative insights in educational settings. For instance, Lloyd (2011) conducted a mixed-methods quasi-experimental study comparing student performance in single-gender and mixed classrooms, drawing on approximately 20 students per class (aggregated across grades and years) to analyze test scores statistically, thereby demonstrating feasible outcomes despite group-level limitations. Similarly, Minkkinen (2022) employed a quantitative quasi-experimental design with 47 high school students across two online classes to evaluate the impact of a learning platform on engagement and achievement through surveys and assessments. Most representatively, Melender et al. (2020) applied a quasi-experimental before-and-after design without a control group, involving 48 health and social care professionals in an evidence-based practice intervention, and relied on nonparametric statistical tests to detect significant changes over time—highlighting how small samples can effectively support exploratory educational research in resource-limited contexts. However, as discussed in educational research syntheses, the small sample is acknowledged as a limitation, potentially reducing generalizability and increasing Type II error risk (Dong & Maynard, 2013).

Intervention

The intervention followed a three-stage, ten-step process (Figure 2) over three semesters (the first and second of 2023–2024 and the first of 2024–2025)..

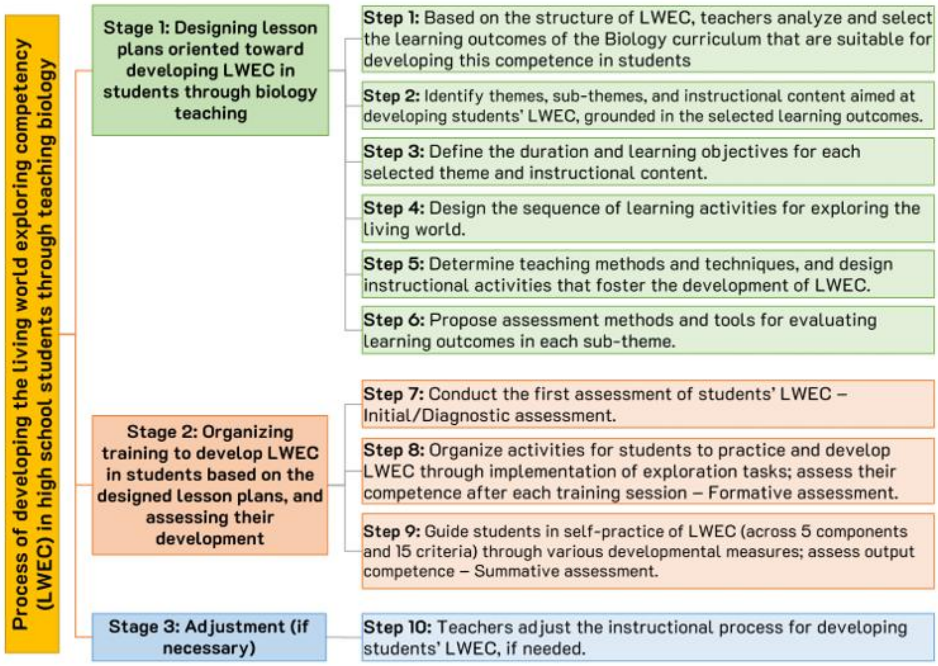

Figure 2
Process integrating RBT for developing students' CELW

RBT was integrated in Step 5 of Stage 1, focusing on biodiversity and ecosystems from the national biology curriculum. Teachers received a one-day workshop on RBT facilitation. Lessons emphasized real-world problems (Example: climate change impacts,…), student-led inquiry, collaboration, and reporting. Low-cost resources (models, microscopes, online simulations, digital devices) were used. Each session lasted 45–60 minutes, twice weekly.

Table 1
Intervention phases and activities

Stage	Step	Description	Duration	Key Activities and Materials
Stage 1: Designing Lesson Plans	1 – 4	Analyze curriculum outcomes, select topics (biodiversity,…), set objectives, and prepare aids.	2 weeks	Curriculum mapping; materials: textbooks, models, microscopes.
	5	Implement RBT: Design inquiry-based activities on real-world problems.	4 weeks	Student-led hypothesis formulation and planning; teacher prompts.
	6	Craft activities for problem-solving and CELW development.	1 week	Group investigations; digital simulations.
Stage 2: Organizing Training and Assessment	7	Initial CELW assessment (pretest).	1 session	Rubric-based evaluation.
	8	Guide practice of CELW indicators via RBT; formative assessments 1-2.	4 weeks	Projects, discussions; reports and presentations.
	9	Independent practice; summative assessment (posttest).	2 weeks	Student proposals and solutions; rubric scoring.
Stage 3: Adjustments	10	Adjust plans based on assessments.	Ongoing	Feedback integration; no new materials.

Data Collection

Data were collected through:

– A preliminary survey was conducted to assess baseline CELW levels and inquiry experience.
– CELW assessments at four points (pretest, two formative, posttest) using a validated 4-point rubric aligned with five CELW components and high reliability ($\alpha = 0.89$).

Data Analysis

Quantitative data from the four assessments across five CELW components were analyzed using SPSS version 21.

– One-way repeated-measures ANOVA examined longitudinal changes within each group, with post-hoc Bonferroni tests for pairwise comparisons.
– Independent t-tests compared mean scores between groups at each point ($p<0.05$).
– Descriptive statistics (means, standard errors) summarized performance.

This approach ensured rigorous evaluation of RBT's impact on CELW across both high- and average-performing students.

FINDINGS

Evaluating the effectiveness of RBT in developing CELW

A pedagogical experiment was conducted with students at An Khanh High School, Can Tho City, to evaluate the effectiveness of the comprehensive three-stage process, which strategically incorporated RBT as a central instructional strategy in Step 5. The development of students' CELW was assessed using an evaluation tool designed to operationalize the five core components of CELW. The instrument included specific behavioral indicators across five criteria, each evaluated on a four-point scale: Level 1 - Below Expectation (M<1.75); Level 2 - Satisfactory (1.75≤ M<2.50); Level 3 - Good (2.50≤ M<3.25); Level 4 - Excellent (3.25≤ M≤4.00). This assessment framework provided a precise, quantifiable measure of CELW development, ensuring consistency and objectivity in evaluating student progress.

Table 2
Evaluation criteria for the CELW

Assessment Criteria	Level 1 (M≤1.75)	Level 2 (1.75≤M<2.50)	Level 3 (2.50≤M<3.25)	Level 4 (3.25≤M≤4.00)
Cri.1. Proposing Problems and Asking Questions	Need suggestions, repeat examples from the teacher	Identify issues with support.	Proactively state-specific, real issues.	Propose new, unique issues with research value.
Cri.2. Formulating Hypotheses and Analyzing Problems	Unclear, speculative.	Has a hypothesis but lacks clear evidence.	The hypothesis is logical and related to biological knowledge.	The creative hypothesis expands and proposes multiple testable possibilities.
Cri.3. Designing and Conducting Experiments	Based on the template, there are many errors.	Independently develop a plan with slight support.	A detailed, logical plan is suitable for the issue.	A creative plan proposing improvements to equipment/methods.
Cri.4. Analyzing Data and Drawing Conclusions	- Only performing individual actions is not accurate. - Taking notes briefly, unable to analyze.	- Following the procedure correctly but lacking flexibility. - Take accurate notes and simple analysis; conclusions are vague.	- Performing skillfully and coordinating well with steps. - Logical analysis, reasonable conclusions, linking biological knowledge.	- Self-adjusting actions, creative in handling situations. - Good synthesis, critically evaluating results, proposing new research directions.
Cri.5. Writing Reports and Presenting Results	Unable to write or present results.	Writing a basic report but lacking detail and clarity.	Writing a clear report that is well-structured and has a scientific presentation style.	Writing a detailed and accurate report, presenting results scientifically with evaluations and recommendations

Note: Level 1 (M<1.75); Level 2 (1.75≤ M<2.50); Level 3 (2.50≤ M<3.25); Level 4 (3.25≤ M≤ 4.00)

This study evaluated the effectiveness of research-based teaching (RBT) in enhancing students' Competency in Exploring the Living World (CELW) at An Khanh High

School, addressing two research questions: (1) To what extent does RBT improve CELW across its five components (problem identification, hypothesis formulation, planning, execution, and reporting)? (2) How does the effect of RBT on CELW differ between high-performing and average-performing students? The findings, derived from a quasi-experimental pretest-posttest design with two intact groups (10 high-performing and 10 average-performing 10th-grade students), are presented below, focusing on quantitative assessment outcomes across four time points (pre-intervention, two formative assessments, and post-intervention).

For the average-performing student group

Figure 3 and Table 3 illustrate the changes in the mean scores of 10 average-performing students across four assessment points. The results indicate that all five criteria (cri.1–cri.5) consistently improved over time, with average scores increasing from level 1 or 2 at the baseline to level 3 by the third assessment. This reflects a significant progression in students' competencies.

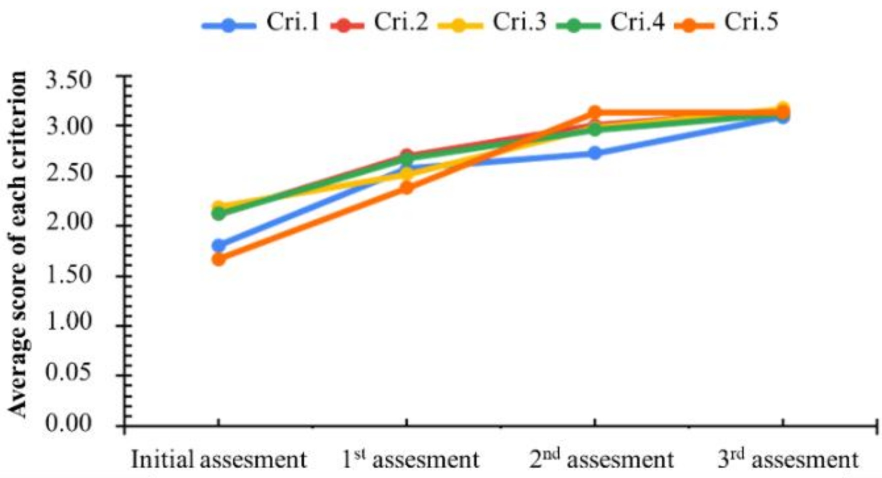

Figure 3
Average scores of 10 average-performing students across 4 assessments

Specifically, as shown in Table 2, all five criteria (cri.1 to cri.5) exhibited steady growth across the assessment points, with the mean scores of average-performing students improving progressively over time. The initial mean scores ranged from 1.70 to 1.96 in the first assessment and increased to between 2.60 and 2.90 by the third assessment, indicating consistent progress. Criterion 5 (application of knowledge and problem-solving) showed the most significant improvement, with the score rising from 1.96 to 3.19 in the final assessment. This marked development suggests that the instructional process positively impacted students' ability to apply knowledge and solve problems.

Table 3
Changes in the average scores of the components in average-performing students across 4 assessments

Criterion	Initial assessment	1st assessment	2nd assessment	3rd assessment	F	p
Cri.1	1.70±0.10[c]	2.53±0.06[b]	2.70±0.06[b]	3.10±0.06[a]	65.50	0.00
Cri.2	1.94±0.12[c]	2.58±0.09[b]	2.87±0.11[ab]	3.09±0.07[a]	25.19	0.00
Cri.3	2.05±0.08[c]	2.45±0.07[b]	2.95±0.07[a]	3.13±0.04[a]	50.32	0.00
Cri.4	1.96±0.08[c]	2.65±0.12[b]	2.94±0.10[ab]	3.13±0.06[a]	29.69	0.00
Cri.5	1.50±0.04[c]	2.40±0.08[b]	3.10±0.06[a]	3.10±0.06[a]	156.45	0.00

Note: Level 1 (M<1.75); Level 2 (1.75≤ M<2.50); Level 3 (2.50≤ M<3.25); Level 4 (3.25≤ M≤ 4.00); Different letters indicate statistically significant differences.

Moreover, the ANOVA analysis revealed that the changes in scores across all five criteria were statistically significant (p = 0.00 for all cases), indicating that the observed improvements were not due to random variation but rather the result of a structured and intentional instructional process. These findings strongly affirm the effectiveness of the teaching approach in enhancing the competencies of average-performing students, particularly in improving their cognitive abilities and scientific problem-solving skills. In summary, the chart and ANOVA results demonstrate a marked improvement in students' competencies, particularly in applying knowledge and problem-solving. This indicates that average-performing students experienced significant development across successive assessment stages.

For the high-performing student group

Figure 4 and Table 4 illustrate the changes in mean scores of 10 high-performing students across four assessment points. This group started at a higher baseline than the average-performing students, with initial scores ranging from level 2 to level 3 in the first assessment. Over the following three assessments, scores across all criteria (Cri.1–Cri.5) increased steadily and consistently, reaching level 3 by the third assessment and approaching level 4. This progression indicates that high-performing students demonstrated strong learning and competency development capacity throughout the instructional process.

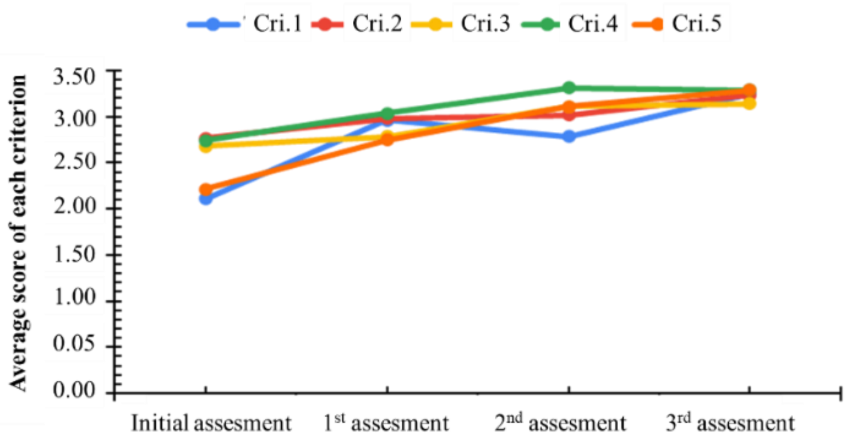

Figure 4
Average scores of 10 high-performing students across 4 assessments

The ANOVA results indicate that the changes across assessment points were statistically significant, with $p < 0.01$ for all criteria. The F-values were notably high, particularly for Criterion 1 ($F = 53.69$) and Criterion 5 ($F = 65.67$), highlighting substantial progress in these components. This reflects marked improvement in cognitive ability and the application of knowledge among high-performing students.

Specifically, Criterion 1 improved from 2.13 to 3.20, and Criterion 5 increased from 2.33 to 3.15, demonstrating significant advancement in applying knowledge in practice. Other criteria also showed steady growth, reaching level 3 by the final assessment, indicating that the instructional process effectively fostered the development of critical thinking, hypothesis formulation, and problem-solving competencies.

Table 4
Changes in the average scores of the components of high-performing students across 4 assessments

Criterion	Initial assessment	1st assessment	2nd assessment	3rd assessment	F	p
Cri.1	$2.13{\pm}0.04^{c}$	$2.90{\pm}0.08^{b}$	$2.80{\pm}0.07^{b}$	$3.20{\pm}0.03^{a}$	53.69	0.00
Cri.2	$2.77{\pm}0.06^{b}$	$3.03{\pm}0.06^{ab}$	$3.16{\pm}0.10^{a}$	$3.28{\pm}0.06^{a}$	9.07	0.00
Cri.3	$2.68{\pm}0.04^{b}$	$2.78{\pm}0.06^{b}$	$3.10{\pm}0.06^{a}$	$3.20{\pm}0.05^{a}$	24.40	0.00
Cri.4	$2.73{\pm}0.04^{c}$	$2.95{\pm}0.07^{b}$	$3.24{\pm}0.04^{a}$	$3.24{\pm}0.04^{a}$	25.71	0.00
Cri.5	$2.23{\pm}0.06^{c}$	$2.63{\pm}0.09^{b}$	$3.15{\pm}0.06^{a}$	$3.28{\pm}0.03^{a}$	65.67	0.00

Note: Level 1 ($M<1.75$); Level 2 ($1.75\leq M<2.50$); Level 3 ($2.50\leq M<3.25$); Level 4 ($3.25\leq M\leq 4.00$); Different letters indicate statistically significant differences.

The chart and ANOVA table show that the high-performing students consistently progressed in competency development across the assessment points. The instructional process had a positive impact, enabling students to enhance their foundational skills and make significant gains in applying knowledge in real-world contexts, with notable improvements in Cri. 1 and Cri. 5.

Comparison between the average and high-performing student groups

The line chart, comparative statistical table (T-test), and bar/column charts tracking changes across four assessment points (ANOVA) provide a comprehensive overview of student development.

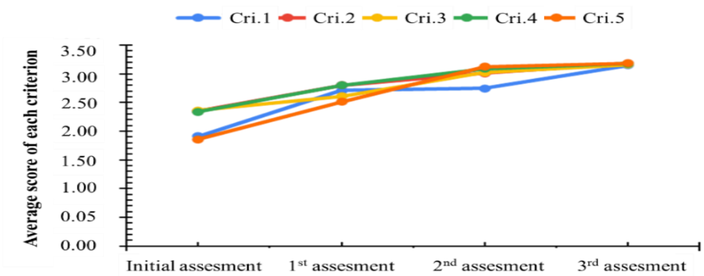

Figure 5
The average scores of 5 components for students at An Khanh High School across 4 assessments

Figure 5 illustrates a marked improvement across all criteria (Cri.1–Cri.5) at each assessment stage, particularly from the baseline (lower scores) to the third assessment (higher scores). The average scores of all criteria showed consistent growth, with a significant increase observed by the third assessment. This suggests that the instructional process positively impacted both student groups, enhancing their competencies and improving their cognitive abilities, analytical thinking, judgment, and applying knowledge to real-life situations.

This improvement was especially notable in Cri. 1 and Cri. 5, where scores showed substantial breakthroughs. These findings reflect a stable and positive development trend across all five criteria, confirming the instructional process's effectiveness in fostering students' competencies in CELW, particularly in critical thinking, hypothesis formation, and real-world knowledge application.

The T-test analysis comparing the average-performing and high-performing student groups revealed a clear distinction. Specifically, the high-performing students consistently achieved higher mean scores than their average-performing peers across all five criteria. This difference was statistically significant, with $p<0.05$ for all cases, indicating that the variation is meaningful.

The ANOVA results (Table 5) showed statistically significant development across all five criteria over the four assessment points when considering the combined sample of 20 students ($p = 0.00$). Each criterion demonstrated substantial and statistically significant growth, affirming that the instructional process had a comprehensive and positive effect on students' CELW development.

Table 5
Comparison of average scores across criteria through 4 assessments

Criterion	Initial assessment	1st assessment	2nd assessment	3rd assessment	F	p
Cri.1	1.70±0.10^{c}	2.53±0.06^{b}	2.70±0.06^{b}	3.10±0.06^{a}	65.50	0.00
Cri.2	1.94±0.12^{c}	2.58±0.09^{b}	2.87±0.11^{ab}	3.09±0.07^{a}	25.19	0.00
Cri.3	2.05±0.08^{c}	2.45±0.07^{b}	2.95±0.07^{a}	3.13±0.04^{a}	50.32	0.00
Cri.4	1.96±0.08^{c}	2.65±0.12^{b}	2.94±0.10^{ab}	3.13±0.06^{a}	29.69	0.00
Cri.5	1.50±0.04^{c}	2.40±0.08^{b}	3.10±0.06^{a}	3.10±0.06^{a}	156.45	0.00

Note: Level 1 (M<1.75); Level 2 (1.75≤ M<2.50); Level 3 (2.50≤ M<3.25); Level 4 (3.25≤ M≤ 4.00); Different letters indicate statistically significant differences.

Specifically, cri.1, cri.2, and cri.3 all exhibited substantial growth. Notably, cri.5 showed the most significant improvement among the average-performing students, indicating their strong potential when guided with explicit and structured instruction in knowledge application.

Among high-performing students, cri.1 and cri.5 recorded high F-values, suggesting that the instructional process significantly enhanced their ability to connect, systematize, and apply knowledge to novel situations. This reflects the group's stronger foundational competencies and higher receptiveness to instructional strategies promoting real-world knowledge transfer.

The consistent outperformance of the high-performing group across all five criteria aligns logically with their stronger initial competencies. However, the significant improvement observed in both groups highlights the overall effectiveness of the instructional approach in enhancing students' competencies. The marked progress in cri.1, 2, 3, and 5 provides robust evidence of the positive impact of the instructional process on all dimensions of CELW.

Moreover, the ANOVA results (Table 6) revealed statistically significant changes in CELW across the four assessment points for both groups (p = 0.00), confirming that these improvements resulted from deliberate instructional intervention rather than random variation.

Table 6
Comparison of average scores through 4 assessments between the two student groups

Group	Initial assessment	1st assessment	2nd assessment	3rd assessment	F	p
Average-performing students	1.83±0.04^{d}	2.53±0.05^{c}	2.92±0.05^{b}	3.11±0.03^{a}	160.40	0.00
High-performing students	2.50±0.00^{d}	2.85±0.04^{c}	3.10±0.03^{b}	3.24±0.02^{a}	160.59	0.00

Note: Level 1 (M<1.75); Level 2 (1.75≤ M<2.50); Level 3 (2.50≤ M<3.25); Level 4 (3.25≤ M≤ 4.00); Different letters indicate statistically significant differences.

Specifically, the average-performing students demonstrated notable development, with their mean scores increasing from 1.83 (Level 2) at the baseline to 3.11 (Level 3) by the final assessment, indicating that these students had achieved an average level of competency in CELW. This reflects the instructional process's substantial impact on enhancing students' cognitive and problem-solving abilities, starting from low or moderate competency levels. In contrast, the high-performing students increased from 2.50 (Level 3) to 3.24 (approaching Level 4), indicating significant advancement toward a high level of competency. This group maintained their strong performance and made further progress, approaching advanced proficiency in critical thinking and knowledge application.

The score progression from Level 2 to Level 3 among average-performing students and from Level 3 to nearly Level 4 among high-performing students is compelling evidence of the effectiveness of the instructional process. It demonstrates that the intervention enabled students to meet the standard competency benchmarks and advance toward higher performance levels. In conclusion, the ANOVA results confirm that the instructional process had a comprehensive and practical impact on students' CELW development, particularly in enhancing cognitive foundations, procedural skills, and the ability to apply knowledge in real-life contexts.

DISCUSSION

The findings demonstrate that integrating RBT into biology instruction significantly enhanced students' CELW at An Khanh High School, with notable improvements across all five components (problem identification, hypothesis formulation, planning, execution, and reporting) and differential effects between high- and average-performing students. However, a key limitation must be acknowledged upfront: the small sample size ($n = 20$) constrains the generalizability of the results. This limitation, shaped by logistical and ethical considerations in a single-school pilot study, may increase the risk of Type II errors and restrict the applicability of the findings to broader contexts (Dong & Maynard, 2013). Readers should therefore interpret the outcomes with caution. Despite this constraint, these results align with constructivist learning theory, which posits that active knowledge construction through inquiry fosters deeper understanding and transferable skills (Arega & Hunde, 2025; Pedaste et al., 2015). The inquiry cycle framework further explains the structured progression from problem identification to communication, as students engaged in iterative scientific processes mirroring authentic research (Pedaste et al., 2015). Below, key findings are compared with prior studies, contextualized within Vietnamese education.

Improvement in CELW Across Components

The significant improvement in CELW scores across all components ($F = 25.19$–156.45, $p = 0.00$) supports the hypothesis (H1) that RBT enhances scientific competencies, consistent with empirical evidence from recent studies. Kaçar et al. (2021) meta-analyzed 32 studies, finding that inquiry-based learning (IBL) significantly boosts academic achievement in secondary science (effect size = 0.72), particularly through hands-on activities like those used in this study's ecosystem-focused lessons. Similarly, Urdanivia Alarcon et al. (2023) reviewed 51 studies, reporting enhanced scientific reasoning via RBT, with 36 focusing on environmental topics relevant to CELW, such as biodiversity analysis. Chengere et al (2025) found guided inquiry labs improved high school students' process skills (e.g., hypothesizing, data analysis) by 20–30%, mirroring the gains in Cri.2 (hypothesis formulation) and Cri.4 (execution) observed here. Chau et al. (2024) reported comparable improvements in problem-solving using the 5E model in Vietnamese middle schools, aligning with this study's structured inquiry approach.

The marked improvement in Cri.5 (reporting and communication, F = 156.45) is particularly noteworthy, as it reflects students' ability to synthesize findings into coherent narratives, a skill emphasized in competency-based frameworks (Constantinou et al., 2018; Sahintepe et al., 2020; Spence et al., 2020). Spence et al (2020) found that IBL enhanced scientific thinking through peer-reviewed presentations, similar to this study's group projects and presentations. This finding extends prior work by showing that structured RBT can foster communication skills even in resource-constrained settings like Vietnam, where traditional teaching often prioritizes rote learning (Ho & Dimmock, 2023). However, unlike Chang et al (2023), who emphasized mobile-enhanced inquiry for autonomy, this study relied on low-cost materials (e.g., microscopes, local ecosystem observations), suggesting that RBT's efficacy is not solely dependent on advanced technology, which is critical for scalability in developing contexts.

Differential Effects Between Student Groups

The second research question revealed that high-performing students achieved greater CELW gains than average-performing students (H2), with significant differences ($p < 0.05$) across all assessments. High-performers' baseline scores (Level 2–3) and final scores approaching Level 4 align with (Cairns, 2019), who found open inquiry enhances metacognitive skills in advanced biology students, particularly in problem identification (Cri.1). Peters-Burton et al. (2022) noted that students with stronger prior knowledge benefit more from inquiry's autonomy, as seen in high-performers' gains in Cri.5 (reporting), where they proposed creative solutions. In contrast, average-performing students' progress from Level 1–2 to Level 3, especially in Cri.5, supports Thuan and Son (2025), who reported IBL's efficacy for moderate performers in Vietnamese schools when guided scaffolding is provided. This aligns with constructivist principles, where scaffolded inquiry supports diverse learners by building on existing knowledge (Arega & Hunde, 2025).

The differential effect may reflect prior knowledge as a moderator, as hypothesized, with high-performers leveraging stronger foundations to navigate open-ended tasks (Strat et al., 2024). This study's structured ten-step process, with teacher guidance, likely mitigated such barriers, enabling significant progress for average-performers, a finding that extends prior work by highlighting the role of explicit scaffolding in resource-limited contexts.

CONCLUSION

This study demonstrated that integrating RBT into biology instruction significantly improved high school students' CELW at An Khanh High School. Both average- and high-performing students achieved meaningful gains across all CELW components, particularly in scientific reasoning and communication, with high-performers showing greater advancements due to stronger prior knowledge. The instructional model effectively accommodated diverse learners while promoting deep engagement with real-world biological problems. These findings suggest that RBT is a viable and scalable strategy for competency development in secondary science education, particularly in resource-constrained contexts like Vietnam, aiming to align curricula with inquiry-based, student-centered learning.

The implications of this study are twofold. Theoretically, it reinforces constructivist learning theory by demonstrating how inquiry-based processes enhance scientific competencies, thereby contributing to the global discourse on effective science education practices. Practically, it provides a model for Vietnamese educators to integrate RBT into biology curricula using low-cost resources, supporting national reforms toward competency-based education. To extend these findings, three directions are recommended: (1) integrating RBT into teacher professional development through workshops on inquiry scaffolding and effective use of low-cost resources to support diverse learners; (2) piloting RBT in national biology curricula through small-scale implementations focusing on local ecosystem topics to overcome resource barriers; and (3) conducting longitudinal studies across diverse Vietnamese schools to evaluate RBT's long-term impact on CELW retention and generate evidence for scalable policy reforms. Collectively, these steps can enhance equity and advance competency-based science education in Vietnam and beyond.

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