Designing Competency-Oriented Learning Games for Grade 3 Natural and Social Sciences: Supporting Observation, Evidence-Based Reasoning, and Problem Solving

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ABSTRACT

Learning games are common in primary classrooms, yet they are often used mainly for motivation or review rather than as structured environments for inquiry. This study developed and preliminarily evaluated a competency-oriented system of learning games for Grade 3 Natural and Social Sciences in Vietnam. The study comprised three phases: a descriptive needs analysis with 32 teachers and 118 Grade 3 students; development of a five-step design process and a 12-game system; and a seven-lesson quasi-experimental pilot with 77 students in two intact classes (experimental n = 41; control n = 36). For international interpretation, the original inquiry indicators were analytically mapped onto three interconnected functions: purposeful observation; evidence-based reasoning, including simple prediction or judgment when tasks permitted; and contextual problem solving. The mapping was conceptual and did not create new psychometric subscales. Before the intervention, no statistically significant difference in total test scores was detected between groups, Welch's $t(74.57) = 0.30$, $p = .763$, $d = 0.07$. At post-test, the experimental class scored higher ($M = 8.22$, $SD = 1.13$) than the control class ($M = 7.06$, $SD = 1.35$), Welch's $t(68.55) = 4.07$, $p < .001$, 95% CI [0.59, 1.73], $d = 0.94$. Process records indicated that the intervention created more structured opportunities for students to generate questions, record observations, justify classifications, and defend decisions. Because the available dataset contains total scores rather than validated skill-specific subscales, the findings support the feasibility and integrated inquiry value of the system, not separate causal effects on observation, reasoning, or problem solving.

Keywords: game-based learning; inquiry competence; evidence-based reasoning; problem solving; primary education

INTRODUCTION

Primary science-related learning requires more than factual recall. Young students need repeated opportunities to notice relevant features, formulate questions, collect and organize information, interpret evidence, and use that evidence to make judgments or address contextual problems. Inquiry-based learning frameworks describe these actions as interconnected processes that may include orientation, conceptualization, investigation, interpretation, conclusion, communication, and reflection (Pedaste et al., 2015). Research on primary science inquiry assessment likewise indicates that analytical, planning, interpretation, and science-knowledge dimensions can be meaningfully distinguished while remaining closely related (Pedaste et al., 2021).

Game-based learning may provide a productive environment for such processes because games can combine goals, rules, challenge, feedback, repeated action, and social interaction within a coherent task. However, learning does not follow automatically from competition or enjoyment. Garris et al. (2002) emphasized the game cycle and debriefing as mechanisms that connect game activity to learning, while Plass et al. (2015)

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argued that effective game-based learning depends on alignment between game design and cognitive, motivational, affective, and sociocultural learning processes. A systematic review in primary education similarly found generally positive potential but considerable variation according to content, design, implementation, and outcome measures (Hainey et al., 2016).

A persistent classroom problem is that games may be used for relatively low-demand instructional functions. Letina (2021), surveying 349 primary teachers in Science and Social Studies, reported that games were used most often to motivate students and practise skills, and much less often for formative assessment or higher-level learning outcomes. In science education, Li and Tsai (2013) also found that game-based studies were concentrated more heavily on knowledge and concepts than on scientific processes and problem solving. The central design issue is therefore not whether students enjoy a game, but whether the game's mechanics require the cognitive actions that constitute inquiry.

The Vietnamese Grade 3 subject Natural and Social Sciences provides a relevant context because the national curriculum emphasizes questioning, observation, simple practical investigation, comparison, classification, evidence-based comments, and application to everyday situations (Ministry of Education and Training [MOET], 2018). Vietnamese scholarship has already explored the use of learning games in this subject. For example, Ta and Tran (2023) proposed a design process for Grade 3 games targeting inquiry competence, while Pham and Ly (2024) examined the use of folk games in Grade 2 Natural and Social Sciences. Accordingly, the present study does not claim to be the first Vietnamese study on learning games in the subject. Its intended contribution is narrower: to systematize the alignment among curriculum outcomes, observable inquiry actions, game mechanics, evidence products, and assessment criteria, and to examine the feasibility of this system in a short quasi-experimental pilot.

The underlying study operationalized inquiry competence into three clusters: T1 - questioning and identifying what needs to be investigated; T2 - observation, practical activity, and information collection; and T3 - comparison, evidence-based comment, and presentation. For the present article, these indicators are analytically organized around three internationally interpretable functions: purposeful observation; evidence-based reasoning, including simple prediction or judgment when the task permits; and contextual problem solving. This reorganization is a conceptual mapping rather than a claim that three new psychometric constructs were directly measured.

Three research questions guided the article: (RQ1) What classroom-use patterns and pedagogical barriers justify a competency-oriented game system in Grade 3 Natural and Social Sciences? (RQ2) What design process and game families can align game mechanics with observation, evidence-based reasoning, and problem solving? (RQ3) What preliminary evidence of feasibility and integrated inquiry-task performance emerges from a seven-lesson quasi-experimental pilot?

CONCEPTUAL FRAMEWORK

From playful activity to epistemic participation

Game-based learning should be distinguished from gamification. Gamification refers to the use of game-design elements in non-game contexts (Deterding et al., 2011), whereas game-based learning uses a game as the learning environment or task. In this study, the design unit is the learning game itself: a bounded activity with a goal, a cognitive task, rules, interaction, feedback, and an observable product.

The core design premise is that successful play should depend on the target cognitive action. If a game aims to support observation, points should depend on accurately noticing and recording features rather than on speed alone. If the target is evidence-based judgment, a classification or choice should count only when students provide a relevant reason. If the target is contextual problem solving, the game should require students to identify the issue, obtain or select evidence, choose or propose a response, and justify that response. In this way, game mechanics function as epistemic rules rather than decorative additions.

Learning-through-play literature highlights active engagement, meaningfulness, iteration, social interaction, and enjoyment as characteristics of productive playful experiences (Zosh et al., 2017). In the present framework, these features are treated as enabling conditions. The primary learning evidence remains the student's inquiry action and the product generated through that action.

Operationalizing the three inquiry functions

Purposeful observation refers to directed attention to relevant features of objects, pictures, models, environments, or information sources, followed by the recording or organization of what is observed. This function corresponds most directly to T2.

Evidence-based reasoning refers to the cognitive work that links information to a defensible interpretation. It may include comparison, classification, inference, simple prediction when a task permits it, and judgment supported by observable or recorded evidence. This function draws primarily on T1 and T3. The term is deliberately broader than prediction because unsupported guessing was not an intended learning outcome in the source study.

Contextual problem solving is treated as an integrated sequence rather than an isolated test score: identifying what needs to be resolved, collecting or selecting relevant information, proposing or choosing an appropriate response, and explaining why the response is justified. This function integrates T1-T3 with application to a contextual situation.

Table 1. Analytical mapping from source indicators to article-level inquiry functions

Article-level function	Source indicator(s)	Observable student action	Typical evidence/product
Purposeful observation	T2	Notices relevant features; manipulates objects or representations; records or organizes information	Observation sheet, data table, marked image, station record
Evidence-based reasoning	T1 + T3	Forms a focused question or simple prediction when appropriate; compares, classifies, infers, or judges using evidence	Question/prediction, classification criterion, justification statement
Contextual problem solving	Integrated T1-T3 + application	Identifies a problem; gathers or selects evidence; proposes/chooses a response; explains or defends the decision	Decision sheet, recommendation, proposed action, oral/written defense

METHOD

Research design and participants

The study used a three-phase design-oriented sequence combining descriptive survey data, instructional design development, a quasi-experimental comparison, and classroom process evidence. Phase 1 identified current game-use patterns and design needs. Phase 2 developed a five-step design process and a 12-game system. Phase 3 implemented selected games and structurally similar variants in a seven-lesson pilot. Because the pilot used intact classes without random assignment, its results are interpreted as preliminary and context-bound rather than as definitive causal evidence.

The needs analysis was conducted in December 2025 with 32 teachers who were teaching or had taught Grade 3 and 118 Grade 3 students from primary schools in Bac Ninh, Thai Nguyen, and Phu Tho, Vietnam. The sample was selected according to research access and availability; therefore, the survey findings describe the participating group and are not intended as population estimates.

The pilot was conducted during January-February 2026 at Cach Bi Primary and Lower Secondary School, Bac Ninh Province. It involved 77 students in two intact Grade 3 classes. Class 3A was the experimental group (n = 41; 20 boys, 21 girls) and class 3B was the control group (n = 36; 22 boys, 14 girls). The intervention covered seven lessons from Lessons 15-17 in the Plants and Animals unit. The experimental class used the designed game system and associated instructional measures; the control class studied the same curricular content under the school's usual instructional organization.

Needs-analysis instruments

Teacher and student questionnaires were used descriptively to identify how games were used, which inquiry actions occurred during games, and what difficulties or support needs were reported. Teacher items included single-choice, multiple-response, and five-point response formats. The student questionnaire used simplified wording and focused on frequency, experience, activities performed during games, and difficulties. The questionnaire items were analyzed at the item level; they were not treated as a validated latent scale, and no composite reliability coefficient is claimed in this article.

Teacher results are reported as frequencies, percentages, and item means. Student results are reported as percentages for activities students said they commonly performed during games. The two sources were used for descriptive triangulation of classroom patterns, not for inferential comparisons between teachers and students.

Five-step game-design process

Table 2. Five-step process for competency-oriented learning-game design

Design step	Operational criterion
1. Specify the curriculum outcome and observable inquiry indicator	Translate the curriculum requirement into an observable action such as asking a focused question, recording a feature, comparing evidence, or proposing a justified response.
2. Determine content, instructional purpose, and lesson position	Decide whether the game serves orientation, exploration/knowledge construction, practice, application, or formative assessment. Match the task and success criteria to that purpose.
3. Design the game mechanism	Create the challenge, roles, rules, time, and success criteria. Completion or winning must require the intended cognitive operation; accuracy and evidence take priority over speed.
4. Design materials and evidence products	Prepare objects, pictures, cards, information stations, observation sheets, decision sheets, or checklists so that student thinking leaves an observable trace.
5. Review and refine	Check clarity, safety, timing, participation, and whether the game actually elicits the intended action. Revise rules, roles, workload, or evidence criteria as needed.

Pilot assessment and analysis

Two 35-minute tests were designed with the same scoring blueprint and comparable task structure. Each test was scored on a 10-point scale: 2 points for basic content knowledge and 8 points for inquiry-related tasks. The inquiry component included question generation/problem orientation (T1), reading or recording observational information (T2), comparison/classification with justification (T3), and an integrated problem-evidence-explanation task. The source study did not report psychometric evidence establishing the tests as statistically equivalent parallel forms; this article therefore describes them as structurally comparable rather than psychometrically equivalent.

Process evidence came from classroom observations, task sheets, classification boards, decision sheets, and other student products. These sources were used descriptively to characterize the opportunities and actions

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generated by the intervention. They were not converted into a new quantitative competency score and were not combined mechanically with test scores.

Because the underlying dataset did not retain identifiers that linked each student's pre-test and post-test scores, paired within-student analyses were not possible. Between-group means were compared at pre-test and post-test using Welch's independent-samples t-test. Cohen's d was used to describe standardized mean differences. Class-level mean changes are discussed descriptively only.

RESULTS

Needs analysis

Learning games were familiar to the teacher sample: 71.9% reported using them at least about once per week. However, use was concentrated in warm-up (84.4%) and practice/consolidation (78.1%), with lower proportions reporting use for knowledge construction (40.6%), application/extension (28.1%), and assessment (18.8%).

Teachers reported that purposeful observation (M = 4.22) and comparison/classification (M = 4.05) occurred more frequently in the games they used than systematic data recording (M = 3.02), drawing conclusions or proposing an action (M = 3.11), and questioning/problem identification (M = 2.88). Student responses showed a similar pattern: 78.0% reported commonly observing, 71.2% comparing or classifying, 54.2% explaining a choice, 41.5% recording results, and 38.1% asking questions during games. These descriptive patterns indicate that observation and classification were more visible than the full inquiry sequence of questioning, recording evidence, explaining, and concluding.

Teachers also reported practical design and implementation barriers: insufficient preparation time (71.9%), difficulty aligning games with competency goals (68.8%), classroom-management difficulty (62.5%), and difficulty assessing students during play (59.4%). Their most frequent support requests were sample games by topic (78.1%), a competency-based design process (75.0%), assessment criteria/rubrics (71.9%), and game-linked worksheets (68.8%). These findings directly informed the emphasis on reusable structures, explicit evidence products, and concise assessment criteria.

The 12-game system

The resulting system contained 12 learning games organized into three functional families. Each game linked a curriculum outcome to a cognitive task, rules, an evidence product, and a criterion for successful play.

Table 3. Overview of the 12-game competency-oriented system

Game family	Game	Curricular context	Dominant cognitive demand	Required evidence/product
Problem/question generation	Heritage Reporter	School traditions	Generate focused information-seeking questions	Question set for interviewing/source exploration
Problem/question generation	Fire-Risk Detective	Fire prevention at home	Identify hazards; formulate investigative questions; justify risk	Marked risk locations + questions + reasons
Problem/question generation	Safety Survey Code	School safety	Define a survey problem and an observable guiding question	Problem-question-criterion pairs
Problem/question generation	Health Question Box	Health risks	Generate questions about harm, affected organs, and prevention	Question cards reviewed against criteria

Observation/information collection	School Safety Detective	School safety survey	Observe purposefully; record evidence; propose a recommendation	Location-feature-judgment-evidence-recommendation sheet
Observation/information collection	Plant Detective	Plant parts	Observe visible features and record specific characteristics	Observation sheet with visible evidence
Observation/information collection	Health Information Hunt	Health information	Locate, select, record, and identify the source of relevant information	Source-tagged information sheet
Observation/information collection	Compass Relay	Directions in space	Use a compass or sun cues; observe and record directions	Station task cards + procedure description
Evidence-based reasoning/problem solving	Community Newsroom	Community participation	Judge participation from contextual evidence; communicate a conclusion	Evidence-based short news report
Evidence-based reasoning/problem solving	Evidence-Based Plant Sorting	Plant comparison	Choose a criterion; classify; justify similarities/differences	Classification board + criterion + explanation
Evidence-based reasoning/problem solving	Animals to the Right Team	Animal structures/functions	Classify by locomotion-related structures; justify placement	Animal classification board + reasons
Evidence-based reasoning/problem solving	Smart Choice Council	Reasonable use of plants/animals	Select a response to a contextual problem; provide reasons; defend the decision	Decision sheet + reasons + oral defense

The system was designed around an 'epistemic rule': a response was not fully rewarded unless students produced the evidence needed to justify it. For example, in School Safety Detective, a general statement that a location was unsafe was insufficient without a recorded observable sign and a reason. In Animals to the Right Team, correct classification had to be accompanied by a criterion or structural basis. In Smart Choice Council, choosing an option without justification did not receive full credit.

This structure was intended to move students from noticing to reasoning and, where appropriate, to action. Not every game targeted all inquiry functions simultaneously; rather, the sequence distributed questioning, observation, evidence use, classification, explanation, and contextual decision making across different lessons.

Quasi-experimental pilot

Table 4. Pre-test and post-test total scores by group

Time	Group	n	M	SD	Welch's t (df)	p	95% CI; d
Pre-test	Experimental	41	7.24	1.56	0.30 (74.57)	.763	[-0.59, 0.80]; d = 0.07
Pre-test	Control	36	7.14	1.48			
Post-test	Experimental	41	8.22	1.13	4.07 (68.55)	< .001	[0.59, 1.73]; d = 0.94
Post-test	Control	36	7.06	1.35			

At pre-test, no statistically significant between-group difference was detected, Welch's $t(74.57) = 0.30$, $p = .763$, 95% CI [-0.59, 0.80], $d = 0.07$. This result indicates a very small observed standardized difference at baseline; it should not be interpreted as formal statistical proof of equivalence.

At post-test, the experimental group scored higher than the control group, Welch's $t(68.55) = 4.07$, $p < .001$, 95% CI [0.59, 1.73], $d = 0.94$. In addition, 30 of 41 students in the experimental group (73.2%) obtained scores from 8 to 10, compared with 16 of 36 students in the control group (44.4%).

Classroom records provided descriptive process evidence consistent with the intended design. In the experimental class, several tasks required students to generate their own questions or identify what needed to be found; observation sheets and game cards required information to be recorded before an answer was accepted; and classification or decision games required criteria, reasons, or defense of a choice. In the control class, students also observed and worked individually or in groups, but the available records indicated fewer task structures that required students to document evidence before responding or to justify and defend decisions.

The available data do not support separate quantitative claims about gains in observation, evidence-based reasoning, or problem solving. The tests produced total scores, and the process evidence was descriptive. The statistically significant post-test difference therefore concerns overall performance on the study's combined test, of which 8 of 10 points were inquiry-related, rather than validated subscale gains for the three article-level functions.

DISCUSSION

The principal contribution of this study is a design logic rather than a claim that games are inherently effective. The system embeds target cognitive performance in the rules of play: students receive credit for noticing accurately, recording evidence, explaining a classification, or defending a decision. This operationalizes the alignment principle emphasized in game-based learning theory (Garris et al., 2002; Plass et al., 2015) and addresses the classroom pattern identified by Letina (2021), in which games were more often used for motivation and practice than for higher-level outcomes or formative assessment.

The needs-analysis findings also suggest why observation alone is insufficient. Both teachers and students reported observation and comparison/classification more frequently than questioning and data recording. Inquiry requires these actions to be connected. Pedaste et al. (2015) describe investigation as part of a broader cycle that includes conceptualization, interpretation, conclusion, and discussion; Pedaste et al. (2021) similarly show that primary science inquiry includes multiple related skill dimensions. The game system therefore treats an observed feature as the beginning of a reasoning chain rather than as the endpoint.

The construct label 'evidence-based reasoning' is especially important for maintaining conceptual accuracy. The source study allowed simple prediction when a task permitted it, but it did not measure a stand-alone prediction scale. Moreover, prediction without evidence can collapse into guessing. By placing prediction alongside comparison, classification, inference, and justified judgment, the framework emphasizes that students should connect claims to observable information.

The system also extends prior Vietnamese work without overstating novelty. Earlier studies have already proposed learning games in Natural and Social Sciences, including a Grade 3 design process targeting inquiry competence (Ta & Tran, 2023) and a Grade 2 approach using folk games (Pham & Ly, 2024). The present study adds a more explicit alignment among curriculum outcome, cognitive action, game mechanic, evidence product, and criterion, together with a short classroom pilot. Its contribution is therefore cumulative rather than a claim of an entirely new research direction.

The post-test standardized mean difference was large in the study context. Nevertheless, several features prevent strong causal interpretation: intact classes were used; assignment was not random; the intervention lasted only seven lessons; the sample came from one school for the experimental phase; and individual pre-post records were not linked. A non-significant baseline test also does not establish equivalence. The result is therefore best viewed as preliminary evidence that the intervention is feasible and associated with higher post-test performance under the conditions studied.

Measurement limitations are equally important. The needs-analysis questionnaires were used descriptively and were not validated as multi-item scales. The two achievement tests were structurally comparable, but the source study did not establish psychometric parallel-form equivalence. Most importantly, no validated subscale scores are available for the three article-level functions. Future work should develop skill-specific task clusters, examine reliability and construct validity, retain anonymous linkage codes for paired analysis, and test the framework across more schools and curricular topics.

Finally, implementation quality may matter as much as game design. Inquiry-rich tasks create opportunities for students to articulate assumptions, discuss observations, and explain evidence, but the relationship between instructional support and learning gains is not necessarily simple or uniformly positive. Heppt et al. (2023), for example, found substantial learning gains within inquiry-based elementary science units while observing no robust association between their measured dimensions of teacher instructional support and student outcomes. This cautions against attributing the pilot results to a single mechanism and reinforces the need for more fine-grained implementation research.

IMPLICATIONS FOR PRACTICE AND RESEARCH

For practice, teachers should begin with the intended cognitive action rather than with a preferred game format. The question 'What game can I use?' can be replaced by 'What must students observe, record, infer, justify, or decide?' The game format can then be selected or designed so that the target action becomes necessary for successful play.

Second, evidence products should be brief but mandatory. A short observation row, classification criterion, two-sentence justification, or decision card can turn an ephemeral game response into an assessable learning trace. These products also make formative feedback more feasible.

Third, game systems should distribute cognitive functions across a sequence of lessons. One game may primarily generate questions, another may collect observations, and a later game may require evidence-based decisions. The instructional sequence, rather than each individual game, can create repeated connections among observation, reasoning, and problem solving.

Future studies should extend the duration and number of schools, retain anonymous student linkage codes, validate separate measures for observation, evidence-based reasoning, and problem solving, and examine which game features account for learning effects. Particularly useful tests would compare versions of the same game with and without explicit evidence requirements, or compare cooperative and competitive scoring structures while holding the cognitive task constant.

CONCLUSION

This study developed a 12-game competency-oriented system for Grade 3 Natural and Social Sciences around a simple principle: curriculum outcome, cognitive action, game rule, evidence product, and assessment criterion should be aligned. Under this principle, observation becomes purposeful information collection, prediction or judgment becomes evidence-based reasoning rather than unsupported guessing, and problem solving becomes a visible sequence of identifying an issue, using evidence, selecting an action, and explaining the choice.

The seven-lesson pilot was associated with higher post-test total scores in the experimental class and generated process records showing more structured opportunities for questioning, recording evidence, classification, justification, and decision defense. These findings are promising but preliminary. They support the feasibility and integrated inquiry value of the design system; they do not establish separate causal effects on observation, evidence-based reasoning, or problem solving. Stronger conclusions require longer, multi-site studies with validated skill-specific measures and linked individual pre-post data.

DECLARATIONS

Ethics and consent

The available study materials state that questionnaire information was collected for research purposes and that personal information would be kept confidential. Only anonymized and aggregated results are reported.

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Competing interests

The authors declare no competing interests.

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