

Stealth Assessment of Children's Connection to Nature in a Serious Game

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Abstract: Contemporary societies are experiencing a growing disconnection between children and the natural environment, often described as “nature-deficit disorder.” Measuring children’s attitudes toward nature is therefore important for environmental education. However, traditional self-report questionnaires pose challenges for young learners due to abstract constructs and social desirability bias. This study explores stealth assessment embedded in a serious game as an alternative method for measuring children’s connection to nature. The study adopts an applied developmental design with a correlational validation approach implemented using the Evidence Centered Design (ECD) framework. A web-based serious game titled Tito was developed for this study based on the theoretical structure of the Connection to Nature Index (CNI). The game operationalizes four CNI dimensions—enjoyment, empathy, oneness, and responsibility—through environmental scenarios such as planting seeds, protecting insects and plants, exploring natural soundscapes, and cleaning environmental waste. Behavioral telemetry data were recorded unobtrusively during gameplay without interrupting the player’s experience. Participants included 83 fourth-grade students (aged 10–11) from an elementary school in Tehran. After completing the standard CNI questionnaire, students played the game individually for eight minutes while behavioral logs were collected and analyzed. To complement the quantitative data, qualitative insights were also gathered through brief interviews with participating students and observational notes recorded during gameplay. Pearson correlation analysis revealed a statistically significant positive relationship between the stealth assessment scores derived from gameplay and the traditional CNI scores ($r = 0.33, p = 0.002$). Additional analyses showed significant correlations for all four subdimensions, including enjoyment ($r = 0.28, p = 0.010$), responsibility ($r = 0.27, p = 0.013$), empathy ($r = 0.24, p = 0.028$), and oneness with nature ($r = 0.23, p = 0.036$). Qualitative observations and short student interviews further supported these findings, revealing behavioral patterns and reflections that were consistent with the gameplay indicators used in the stealth assessment. These findings suggest that stealth assessment embedded in serious games can provide a valid and ecologically meaningful alternative to traditional self-report instruments for evaluating children’s connection to nature.

Key words: Serious games, Stealth assessment, Evidence-centred design, Children’s connection to nature

1. Introduction

The modernization of contemporary societies has created an increasing gap between children and the natural world. Modernization—a process characterized by the expansion of technology, industrialization, urbanization, and test-oriented education systems—has separated children’s lived and embodied experiences from their natural environment. This alienation, first conceptualized by Louv (2008) as “nature-deficit disorder,” has, with the unprecedented growth of digital technologies and urban lifestyles, evolved into a global concern in the field of psychological development (Soga & Gaston, 2016; Larson et al., 2019; Gienger et al., 2024).

This disconnection from nature, often intensified by the replacement of “green time” with “screen time” (Oswald et al., 2020), has documented negative effects on various dimensions of human cognitive, emotional, and social development. In response to this challenge, accurately assessing children’s “connection to nature” has become a fundamental prerequisite for designing effective educational interventions.

It is important to note that this disconnection is not a new phenomenon. The earliest systematic empirical evidence of the decline in outdoor play dates back to the early 2000s. Quantitative findings by Clements (2004), based on an intergenerational comparison, showed that the rate of daily outdoor play dropped from 70% in mothers’ generation to 31% among children—a concerning trend that has continued in more recent studies and has further deepened the gap between children and nature.

Moreover, this disconnection poses a serious threat to the development of an “affective relationship with nature.” Cheng and Monroe (2012) argue that if a deep emotional connection to nature is not formed during childhood, individuals are unlikely to take responsibility for environmental conservation in the future.

To address this challenge, the development of a valid tool for assessing children's attitudes is essential. In this context, the Connection to Nature Index (CNI), developed by Cheng and Monroe (2012), is recognized as a leading instrument for quantifying four components: enjoyment, empathy, oneness, and responsibility. However, the use of traditional self-report instruments for children aged 10–11 is associated with significant methodological challenges.

On the one hand, abstract constructs such as "oneness with nature" exceed the cognitive capacities of children at this age, as they are still in Piaget's (1958) concrete operational stage. On the other hand, research indicates that social desirability bias can influence the validity of children's responses (Miller et al., 2015), meaning that children may select socially acceptable answers (e.g., claiming to collect trash) even if such behaviors are not reflected in their actual actions (Van De Wetering et al., 2022). Furthermore, traditional instruments are inherently static and disrupt the continuity of experience, capturing only a snapshot of children's attitudes rather than a dynamic and ongoing process (Smith et al., 2023).

In response to these methodological challenges and with the aim of achieving more objective measurement, the present study proposes the use of a stealth assessment approach based on the Evidence Centered Design framework (Mislevy et al., 2003). In this approach, the serious game functions as a "behavioral laboratory," where children engage with interactive environmental scenarios and challenges. Instead of relying on subjective self-reports, players' moment-to-moment decisions and actions are recorded as behavioral evidence and analyzed accordingly. By removing direct tester intervention and reducing social desirability bias, this method enables the collection of data with higher ecological validity (Shute & Moore, 2018; All et al., 2021).

The present study aims to design and validate a game-based stealth assessment tool for measuring children's connection to nature among 10–11-year-olds. The primary focus is to test the hypothesis that behavioral evidence extracted from gameplay is significantly correlated with scores from the standard CNI instrument and can serve as a valid alternative to self-report measures.

2. Methodology

2.1 Research Design

The present study is developmental–applied in terms of purpose and descriptive–correlational in terms of data collection. It is situated within a post-positivist paradigm, based on the assumption that psychological constructs (such as connection to nature), although not directly observable, can be measured with reasonable approximation through objective and quantitative evidence (i.e., in-game behaviors). The main objective of the study is to validate the designed stealth assessment tool by examining its convergent validity with the standard CNI instrument.

2.2 Participants

The statistical population consisted of all fourth-grade elementary students from Haj Javad Arjmandi School in Tehran (District 14) during the 2025–2026 academic year. The sample included 83 students selected through convenience (or purposive) sampling. Inclusion criteria were:

- parental informed consent and the child's willingness to participate,
- absence of severe visual or auditory impairments,
- basic familiarity with using a computer or tablet, and
- being within the age range of 10–11 years.

2.3 Design Framework: Evidence Centered Design (ECD)

The design of the game and its assessment system was conducted based on the Evidence Centered Design framework (Mislevy et al., 2003). This framework was operationalized across three layers to transform behaviors into measurable data:

- Competency Model: The latent variable "connection to nature" was divided into four sub-constructs—enjoyment, empathy, oneness, and responsibility—based on the theoretical model of Cheng and Monroe (2012), recently supported by Menconi et al. (2025).
- Evidence Model: For each sub-construct, specific behavioral indicators were defined. For example, choosing to avoid crushing insects and plants was considered positive evidence for the empathy

component, while ignoring environmental waste along the path was assigned a negative score for responsibility.

- Task Model: The game scenarios and levels were designed in a way that provided multiple decision-making opportunities to elicit these behaviors.

2.4 Research Instruments

To assess the baseline level of participants' connection to nature and to examine the convergent validity of the game, the Persian version of the standard Connection to Nature Index (CNI) questionnaire developed by Cheng and Monroe (2012) was used. This self-report instrument is a multidimensional construct measuring four main components: enjoyment of nature (Enjoyment), empathy toward living beings (Empathy), sense of oneness with nature (Oneness), and environmental responsibility (Responsibility). Responses were recorded on a 5-point Likert scale.

To establish content validity, the translated Persian version of the questionnaire was reviewed by a panel consisting of 5 experts in psychology, educational technology, and environmental education. They evaluated the items for appropriateness, clarity, and relevance to the target construct. Based on their feedback, necessary revisions were made to clarify certain phrases, ultimately confirming the instrument's content validity. Furthermore, the reliability of the instrument in the present study was confirmed using Cronbach's alpha coefficient ($\alpha = 0.79$), indicating a desirable level of internal consistency.

In addition, to prevent bias, no direct feedback regarding the correctness or incorrectness of environmental behaviors was provided to players during gameplay, ensuring that decisions fully reflected their internal attitudes.

The serious game *Tito* was developed as a web-based application using a customized engine built on HTML5 Canvas and Vanilla JavaScript. This platform was selected due to its cross-platform independence, lack of need for intermediary software installation, and its ability to provide smooth performance) on standard mobile and desktop browsers.

The game's telemetry system was designed based on the stealth assessment approach (Shute, 2011) and records players' behavioral data in real time without interrupting the gameplay experience. The architecture of the telemetry system and the classification of recorded data are illustrated in Figure 1. The output log files are in CSV format and include the variables detailed in Table 1.

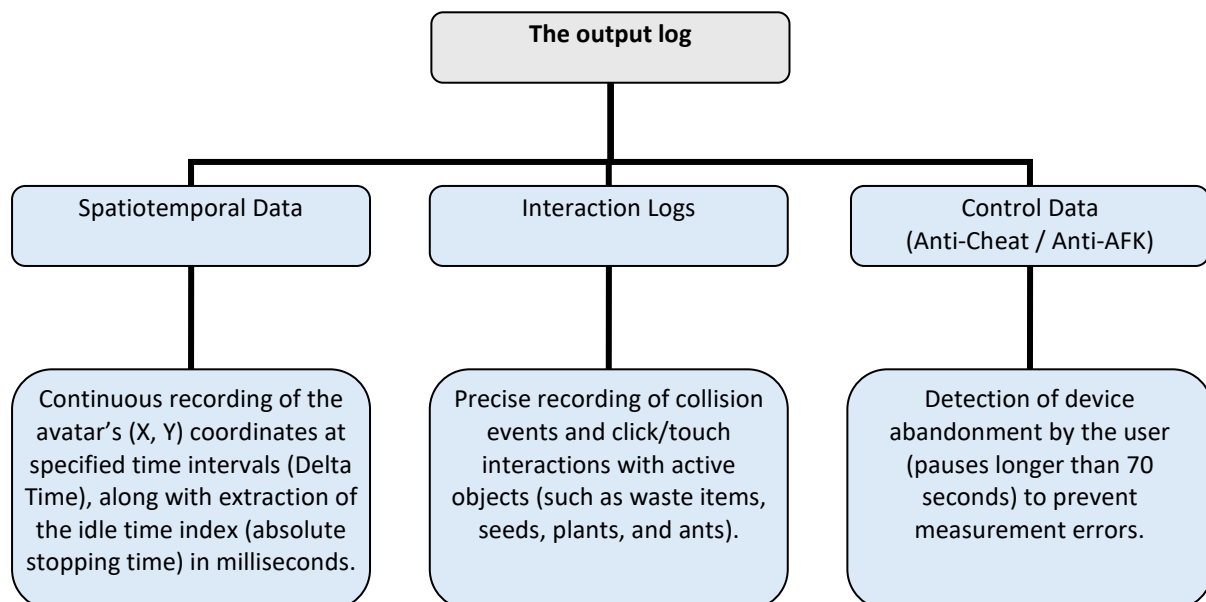


Figure 1: Architecture of the telemetry system and classification of data recorded in log files

Table 1: Mapping In-Game Behavioral Evidence to Connection to Nature Index (CNI) Components

Latent Variable (CNI Component)	Game Scenario	Behavioral Evidence	Scoring Logic
Enjoyment	Exposure to natural “sound zones” (e.g., river and bird sounds) and presence of hidden items in the environment	Voluntary stopping in sound zones to listen, and environmental exploration	Hybrid time-based system: – Calculation of stopping duration (after a 1.5-second delay to filter accidental stops) – Five-level scoring based on duration with Anti-AFK system – Positive points assigned for exploration
Empathy	Presence of vulnerable vegetation (flowers) and insect colonies (ants) along the avatar’s path	Choosing to avoid and navigate around living organisms vs. walking over them (crushing)	Deductive system: – Deduction of 5 points for each crushed flower – Deduction of 10 points for crushing ants (with temporary avatar speed reduction as physical feedback)
Oneness	Availability of seeds and encountering empty, fertile soil spots in the forest ecosystem	Voluntary stopping and interaction to plant seeds and restore the ecosystem	Direct additive system: – +15 points for each successfully planted seed in valid locations
Responsibility	Presence of human-made waste and withered plants located away from water sources	Collecting waste and step-by-step watering of plants until full growth	Capped additive system: – +13 points for each collected waste item – +4 points for each stage of watering plants – Score capped to maintain balanced variable weighting

To provide a clearer visual understanding of the in-game environment and the behavioral choices presented to the player, Figure 2 illustrates examples of the gameplay. These screenshots demonstrate the player’s perspective when encountering the interactive elements mapped to the CNI components, such as navigating vulnerable vegetation and collecting environmental waste.


Figure 2: Gameplay screenshots showing player interaction with the natural environment

3. Procedure

A pilot study with 10 students (aged 10–11) validated game duration ($M = 7.8$ min), reliability ($\alpha = 0.79$), and telemetry logging. In the main study ($N = 83$), participants first completed the Persian CNI questionnaire (paper format) to control order effects. A one-day washout period minimized priming and social desirability bias. Participants then received a brief tutorial and played *Tito* individually for one 8-minute session. Behaviors were

automatically logged via HTML5 Canvas telemetry (CSV format) without participant awareness (stealth assessment).

3.1 Data Analysis

Data were analyzed using SPSS version 28. Normality was tested using the Shapiro-Wilk test, confirming normal distribution for both measures (CNI: $p = 0.12$; Stealth: $p = 0.08$). Convergent validity was examined using Pearson correlation between composite stealth scores (game telemetry) and CNI total/subscale scores. Coefficients were interpreted per Cohen (1988): small ($r = 0.10$), medium ($r = .30$), large ($r = 0.50$); significance at $\alpha = 0.05$.

4. Results

4.1 Quantitative Results

Data from $N = 83$ participants were analyzed. Normality was confirmed for both CNI questionnaire scores and game stealth assessment scores using Shapiro-Wilk tests (both $p > 0.05$), justifying parametric analyses.

4.1.1 Convergent validity

Pearson correlation between total stealth assessment scores and total CNI scores showed a positive, small to moderate, significant association ($r = 0.33$, 95% CI [0.12, 0.51], $p = 0.002$, $r^2 = 0.11$). Subscale correlations (telemetry indicators vs. CNI total) were also positive and significant (Table 2), supporting convergent validity.

Table 2: Pearson Correlation Coefficients Between Components of the Connectedness to Nature Index (CNI) and Game Performance

Component	Correlation Coefficient (r)	Significance Level (p)
Enjoyment	0.28	0.010
Responsibility	0.27	0.013
Empathy	0.24	0.028
Oneness with Nature	0.23	0.036
Note. $N = 83$; all $p < 0.05$.		

4.2 Qualitative Findings

To complement the Evidence-Centered Design (ECD) framework and validate the game's impact on players, qualitative data was collected during the playtesting sessions. Observations and informal interviews were conducted with the participants. Thematic analysis of the students' feedback revealed that the game's mechanics successfully evoked responses aligning with the four components of the Connectedness to Nature Index (CNI). A summary of the representative quotes and observational data is presented in Table 3.

4.2.1 Enjoyment of nature

The gamified elements, such as using the telemetry system to track animals, created a highly engaging environment. Students expressed genuine excitement when interacting with the natural elements presented in the game scenarios. As one student noted:

"It was really fun trying to figure out what to do in the jungle and seeing rabbits jumping around and birds singing we got close to the trees. It felt like a real adventure in the wild." (Student 2)

4.2.2 Empathy for creatures

The game successfully fostered emotional connections between the students and the virtual wildlife. When encountering scenarios where nature faced environmental challenges, players displayed visible concern.

"I felt so bad when I wasn't careful and stepped on the flowers. It even happens to me little sister sometimes when we go to the park. We should be more careful!" (Student 5)

4.2.3 Oneness with nature

Through immersive gameplay, players began to recognize the interconnectedness between human actions and natural habitats. Observations indicated that students felt they were a part of the ecosystem rather than just outside observers.

"The game made me realize that changes in the forest affect us and the animals equally. We share the same space." (Student 8)

4.2.4 Sense of responsibility

The decision-making mechanics within the game prompted students to consider the consequences of environmental actions. The qualitative data showed a strong emergence of protective attitudes.

"Next time I go to the park, I am going to be more careful about where I walk and throw my trash so I don't hurt any animals' homes." (Student 3)

5. Discussion

The present study aimed to design and validate a game-based stealth assessment tool for measuring the Connection to Nature Index (CNI) in children. The findings showed that behavioral data extracted from gameplay exhibited a positive and moderate correlation ($r = 0.33$) with scores from the traditional questionnaire. This finding is consistent with the theoretical foundations of the Evidence Centered Design framework developed by Mislevy et al. (2003), indicating that the evidence model designed in this game successfully linked micro-level player behaviors to macro-level psychological constructs.

One of the most important findings of this study is the nature of the obtained correlation ($r = 0.33$). Although higher correlations are typically expected in classical psychometric approaches, in the context of multimodal studies and stealth assessment, this level of correlation represents a meaningful scientific achievement. This can be explained by the fundamental differences between the two instruments: traditional questionnaires such as the CNI measure idealized attitudes and cognitive perceptions, which are highly susceptible to social desirability bias (Baxter, 2004)—particularly in children, who tend to select responses perceived as "correct" by adults (Van De Wetering et al., 2022).

In contrast, game-based assessment captures real-time, authentic behavior without such biases. Therefore, the observed moderate correlation suggests that both instruments measure a shared construct (connection to nature), while the game-based tool captures more implicit and less contaminated behavioral variance that is not accessible through self-report measures.

Furthermore, analysis of the four dimensions showed that correlations for individual components (e.g., empathy and oneness) were slightly lower than the total score (below 0.30). From a statistical and methodological perspective, this is expected: a smaller number of items and behavioral observations in subcomponents naturally reduces variance, leading to lower correlation coefficients. Nevertheless, the statistical significance of all components ($p < 0.05$) confirms that abstract environmental constructs were effectively operationalized through meaningful gameplay mechanics.

This study, while emphasizing its exploratory nature and the limitations arising from its initial focus on convergent validity, acknowledges that the internal reliability and temporal stability of the game scores require further investigation using more advanced methods. The relatively low correlations observed ($r = 0.23$ – 0.33) are interpreted not as an indication of weakness in the instrument, but rather as reflecting the inherent differences between measuring behavior within a game context (indirect and dynamic) and traditional self-report instruments (subjective and static), as well as the possible influence of other latent constructs (such as game-related skills) on the results. Given the limited sample size and the nature of the study, the generalizability of the findings requires broader investigations with larger samples and multifactorial analyses. Nevertheless, the primary aim of this research was not to standardize the instrument, but to develop an innovative game-based platform grounded in "stealth assessment" to extract valuable behavioral data and to demonstrate the feasibility of this novel approach for assessing nature-related psychological constructs.

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Ethics Declaration: This study was conducted in accordance with the ethical standards of Allameh Tabataba'i University for low-risk educational research. As the study involved only standard educational activities (a digital game and a questionnaire), posed no physical or psychological harm to participants, and collected data

anonymously without any identifying information, it was classified—according to the university’s internal guidelines—as exempt from formal ethics committee review.

AI Declaration: During the preparation and writing of this article, the authors used the artificial intelligence tool Gemini 3.1 Pro exclusively for improving textual readability, language editing, and structural coherence. All AI-generated suggestions were carefully reviewed and critically revised by the authors, who assume full responsibility for the accuracy, validity, and final content of the manuscript. It is explicitly stated that no AI tools were involved in the research design, data collection, statistical analysis, or interpretation of findings, and all reported results are solely based on original empirical data and real participant interactions.

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