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# Usability and educational impact of IndagApp: A virtual tool for inquiry-based science learning in secondary education

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**Abstract**

This study evaluates the effectiveness and usability of IndagApp, a 3D application designed to support inquiry-based science education across different secondary education levels in Spain. The sample comprised 82 students from a public school, including first-year and third-year secondary education students, and first-year baccalaureate students. Using app usage metrics, student performance was assessed through various error types related to hypothesis formulation, variable selection, simulation tasks, and question interpretation. Additionally, the Spanish version of the computer system usability questionnaire was employed to evaluate user satisfaction. Results indicate a general improvement in inquiry skills with educational progression, as reflected by decreasing error rates in most app metrics. Usability scores were generally positive, with high ratings in overall satisfaction, system usefulness, and information quality. IndagApp proves to be an effective and user-friendly tool for fostering scientific inquiry competencies in secondary education, supporting diverse learning needs and promoting engagement through structured digital inquiry experiences.

**Keywords:** IndagApp, inquiry-based learning, science education, educational technology, app usability, virtual labs

## INTRODUCTION

Information and communication technology has become an increasingly pervasive force in various aspects of human life, including its integration into educational environments. In light of the global commitment to fostering 21st century skills, particularly digital literacy as a core objective, there is a growing and justified trend toward incorporating a wide range of educational technologies into the classroom. Researchers and educators worldwide acknowledge that the integration of technology into teaching practices holds the potential to transform learning by providing teachers and students with access to diverse and relevant resources (Timotheou et al., 2023). Through educational technology, immersive and interactive environments can be created to enhance and enrich the learning experience, often surpassing the effectiveness of traditional instructional tools (Wang & Huang, 2025). The value of these technologies lies in their capacity to foster critical thinking, shifting students away from rote memorization and toward a deeper understanding of concepts and their real-world applications (Byukusenge et al., 2022).

Undoubtedly, the teaching of biology, like that of other scientific disciplines, requires the integration of laboratory work as a fundamental component for developing practical skills (Sshana & Abulibdeh, 2020). Many core aspects of biology rely heavily on hands-on activities, particularly within laboratory settings. Research has shown that laboratory experiences can significantly enhance students' intellectual capacities, such as critical thinking, scientific inquiry, and practical competence. Moreover, engaging in laboratory-based tasks has been associated with increased student motivation, which in turn improves academic performance and enriches the overall learning experience (Tuyishime & Tukahabwa, 2022). However,


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**Contribution to the literature**

- This study extends the literature on inquiry-based science education by evaluating a novel 3D digital tool, IndagApp, across multiple secondary education levels.
- Unlike prior research, which often focuses on traditional methods or single-level interventions, this work combines app-based performance metrics with standardized usability assessments to provide a comprehensive evaluation of both learning outcomes and user experience. The findings demonstrate that IndagApp not only enhances inquiry competencies but also achieves high usability ratings, highlighting its potential to support diverse learners.
- By integrating performance data with usability measures, this study contributes a methodological advancement to the field and offers evidence-based insights for implementing digital inquiry tools in science education.

the implementation of such practical activities often encounters a range of challenges. A major obstacle is the time constraint imposed by an extensive theoretical curriculum and limited classroom hours available for laboratory sessions. Additionally, many schools lack adequately equipped laboratory facilities, hindering the delivery of effective hands-on experiences. Resource limitations, both in terms of materials and staffing, also restrict the quality and depth of laboratory instruction. Finally, large class sizes in compulsory secondary education (ESO), typically comprising 20-25 students per group, further complicate the effective management and execution of laboratory activities.

One promising approach to addressing the aforementioned challenges, although it cannot fully replace traditional hands-on laboratory experiences, is the use of technology-based educational resources. In particular, virtual laboratories and computer-simulated experiments have proven effective as alternative or preparatory activities for hands-on work in both secondary and higher education biology courses (Ali et al., 2022; Ngema & Motlhabane, 2025;). These simulated environments serve as valuable tools for conducting scientific investigations in a virtual setting (Abdelmoneim et al., 2022). By employing mathematical models and algorithmic representations, they enable analytical exploration of problems and facilitate the prediction of real-world system behaviors based on specific parameters and initial conditions (Rivas et al., 2020). The use of virtual and simulation-based experiments has been shown to improve students' academic performance and conceptual understanding (Al-Duhani et al., 2024; Aripin & Suryaningsih, 2020). A growing body of research highlights their potential to clarify complex biological concepts and increase student engagement, while also reducing the need for sophisticated and costly laboratory equipment (Coleman & Smith, 2019).

The use of interactive laboratories in education offers several pedagogical advantages, as documented in the literature. For example, virtual labs provide a visual and immersive environment that facilitates the teaching of complex theoretical concepts, such as the structure of molecules, atoms, or biological cells, thereby enhancing student comprehension (Maglio et al., 2025; Setyowati et al., 2023). These platforms also offer a risk-free setting in which students can conduct experiments and explore different approaches without the concern of damaging equipment or materials (Lisborg, 2021). Furthermore, interactive labs help capture students' attention, promoting sustained engagement and motivation throughout the learning process (Spencer et al., 2024). They also support self-paced learning, as students can access and perform laboratory activities anytime and from any location (Aljuhani et al., 2018).

The potential benefits of interactive laboratories have sparked significant research interest, resulting in numerous empirical studies evaluating their effectiveness (Ali et al., 2022; Navarro et al., 2024; Santos & Prudente, 2022). However, most of this research has focused on subjects such as physics, chemistry, and engineering, while considerably less attention has been given to the role of interactive laboratories in biology education (Başer & Durmuş, 2010; Mutlu & Acar-Şeşen, 2018). This gap in literature motivated the selection of IndagApp as the educational resource evaluated in the present study. Developed by faculty members from the universities of Burgos and Valladolid (Spain), IndagApp enables students to conduct virtual scientific investigations on various biology topics. The app guides learners through the phases of scientific inquiry and aligns with the competencies and practices emphasized in the Spanish national education framework, specifically those outlined in organic law 3/2020 of December 29 (which amends organic law 2/2006 of May 3, on education, known as LOMLOE, 2020). This educational tool aims to foster students' scientific competence by supporting the development of key skills such as formulating research questions and hypotheses, manipulating and controlling variables, recording and organizing data, constructing tables and graphs, interpreting results, and drawing evidence-based conclusions. Therefore, the aim of this study is to evaluate the usability and educational effectiveness of IndagApp, a virtual inquiry-based learning tool for biology, among students in secondary education and

baccalaureate. With this objective in mind, we have formulated the following research questions:

1. To what extent does IndagApp contribute to the development of students' inquiry-based science competencies across different levels of secondary education and baccalaureate?
2. How do students' patterns of errors in hypothesis formulation, variable selection, simulation performance, and question interpretation vary according to their educational stage?
3. What are students' perceptions of IndagApp's usability and overall user experience, as measured through the computer system usability questionnaire (CSUQ), and how do these perceptions relate to their learning outcomes?

## MATERIALS AND METHODS

### App Description

IndagApp is a 3D educational application aimed at promoting inquiry-based science learning for students aged 10 to 16, typically in the upper elementary, middle school and high school levels (Yánez-Pérez et al., 2024a). It is compatible with Android devices running version 5.0 or higher, as well as Windows PCs with version 7 or above. IndagApp offers 10 inquiry-based modules exploring various scientific phenomena, including: plant growth, crystal formation, forces, flooding, bacterial growth, photosynthesis, buoyancy, valley formation, light refraction, and balloon flight. The app provides an accessible, interactive, and pedagogically grounded tool designed for both secondary and elementary students. It guides learners through the inquiry process with instructional videos, textual explanations, and a virtual assistant that clarifies key scientific concepts, such as hypothesis formulation and the identification of dependent, independent, and control variables.

IndagApp supports multiple levels of inquiry learning, from structured inquiry, where research questions and experimental procedures are provided, to guided inquiry, where students design their own experiments. Through virtual experiments and simulations, the app enables students to conduct scientific investigations despite limitations like lack of laboratory access or resources, fostering active learning and scientific reasoning in a risk-free environment. This approach aligns with the Spanish LOMLOE educational framework, promoting key competencies including hypothesis development, variable manipulation, data recording, graphical representation, interpretation of results, and drawing conclusions. Usability evaluations with pre-service and in-service teachers have demonstrated that IndagApp offers a positive user experience characterized by ease of use and pedagogical effectiveness, supporting its role as a valuable resource to enhance inquiry-based learning across educational levels (Yánez-Pérez et al., 2024a,b).

### Study Design

#### *Participants*

Participants for this study were selected during the 2022/2023 academic year. The sample consisted of 43 first-year secondary education students (23 females and 20 males, aged 13 to 14), 27 third-year secondary education students (16 females and 11 males, aged 14 to 15), and 12 first-year baccalaureate students (7 females and 5 males, aged 16 to 17) from a public school in Valladolid, Spain.

#### *Data collection*

The instruments used in this study included the following:

**App usage metrics:** To evaluate the effectiveness of IndagApp, various metrics related to student performance were analyzed. The collected data included errors made by students in different aspects of inquiry-based activities across educational levels. The analysis focused on the following variables:

- H0: Number of incorrect responses when identifying factors in hypothesis formulation.
- VAR1, VAR2, VAR3, and VAR4: Errors made when selecting independent, dependent, and control variables.
- SIM1, SIM2, SIM3, and SIM4: Errors committed during simulations involving different hypotheses.
- H1, H2, H3, and H4: Mistakes made when answering interpretation questions related to the hypotheses.
- Inter.: Number of attempts required to correctly answer five questions after testing a hypothesis.
- Afianz.: Number of attempts needed to correctly answer four final content reinforcement questions after completing all four hypotheses in an inquiry activity.

Finally, as a proxy for student engagement, the completion rate (both partial and total) was calculated.

**Usability:** The Spanish version of the CSUQ version 3, consisting of 16 items (see **Table 1**), was administered using a 7-point Likert scale, where 1 indicates strong disagreement and 7 indicates strong agreement (Sauro & Lewis, 2016). The CSUQ is widely used for usability assessments of mHealth technologies (Hajesmaeel-Gohari et al., 2022; Lewis, 2018). The questionnaire has been validated in Spanish, demonstrating a high reliability with a Cronbach's alpha of 0.96 (Barajas-Bustillos et al., 2019; Hedlefs Aguilar & Garza Villegas, 2016; Llorens-Vernet & Miró, 2020). Additionally,

**Table 1.** List of questions of the Spanish version of the CSUQ version 3

| No | Question |
|---|---|
| 1 | In general, I am satisfied with how easy it is to use the educational application IndagApp. |
| 2 | It was simple to use this educational application. |
| 3 | I am able to complete my work (acquisition of inquiry skills) quickly using this educational application. |
| 4 | I feel comfortable using the educational application IndagApp. |
| 5 | It was easy to learn how to use this educational application. |
| 6 | I believe I became proficient quickly using this educational application. |
| 7 | The educational application IndagApp displays error messages that clearly tell me how to solve problems. |
| 8 | Whenever I make a mistake using this educational application, I resolve it easily and quickly. |
| 9 | The information (such as online help, on-screen messages, etc.) provided by this application is clear. |
| 10 | It is easy to find the information I need in this educational application. |
| 11 | The information provided by this educational application was effective in helping me complete tasks. |
| 12 | The organization of the information on the application's screen was clear. |
| 13 | The interface (graphical window) of the educational application IndagApp was pleasant. |
| 14 | I enjoyed using this educational application. |
| 15 | The educational application had all the tools I expected it to have. |
| 16 | Overall, I was satisfied with the educational application. |

participants were given the opportunity to provide open-ended comments at the end of the form.

Using all the scores obtained from the CSUQ questionnaire, four different domains were calculated: overall (OVERALL: the average of responses to items 1-16, encompassing all items); system usefulness (SYSUSE: the average of responses to items 1-6); information quality (INFOQUAL: the average of responses to items 7-12); and interface quality (INTERQUAL: the average of responses to items 13-15).

### *Data analysis*

Descriptive statistics were obtained using R (version 4.4.1) to analyze the quantitative data from both instruments (app usage metrics and usability), calculating values for the different educational levels. To examine differences among the three educational levels analyzed (first-year secondary education, third-year secondary education, and first-year baccalaureate), hypothesis tests were conducted on the app usage metrics and the usability domains. Normality of the data was assessed using the Shapiro-Wilk test ($n < 50$). The significance values (p-values) were interpreted with a 5% significance level (p-value < 0.05 indicating normal distribution; p-value > 0.05 indicating non-normal distribution). Since none of the numerical variables met the normality assumption, the non-parametric Kruskal-Wallis test was applied. This test evaluates whether there are significant differences in the distributions among groups without assuming a specific distribution. When statistically significant differences were detected in the overall analysis (p-value < 0.05), post hoc pairwise comparisons were performed using the Dunn test with Bonferroni correction to identify which groups differed. To assess the magnitude of the differences between groups, Cohen's d was calculated. Cohen's d was computed based on the mean difference divided by the pooled standard deviation, providing a standardized measure of the effect in terms of standard deviation units.

## RESULTS

Regarding the app usage metrics, a general decline in mean values across the educational stages (1º ESO, 3º ESO, and 1º BACH) is observed for most variables (**Table 2**). Specifically, variables such as H0, VAR1, SIM1, H1, VAR2, SIM2, H2, VAR3, and SIM3 show a progressive decrease from 1º ESO to 3º ESO, reaching their lowest values in 1º BACH. For example, H0 decreases from mean (M) = 1.07 (standard deviation [SD] = 1.02) in 1º ESO to M = 0.67 (SD = 0.86) in 1º BACH, while VAR1 drops from M = 2.73 (SD = 3.73) to M = 0.25 (SD = 0.44) over the same period. However, some variables exhibit more fluctuating patterns. For instance, H3 peaks in 3º ESO (M = 2.56, SD = 4.01), followed by a lower value in 1º ESO (M = 1.83, SD = 2.68), and then decreases again in 1º BACH (M = 1.47, SD = 2.72). Similarly, VAR4 rises from M = 0.57 in 1º ESO to M = 1.42 in 3º ESO, before sharp declining to M = 0.12 in 1º BACH. A comparable trend is seen in H4, which increases markedly from M = 0.90 (SD = 2.23) in 1º ESO to M = 4.17 (SD = 5.75) in 3º ESO, followed by a steep drop to M = 0.88 (SD = 1.27) in 1º BACH.

In contrast, the number of attempts required to correctly answer five questions after testing a hypothesis (Inter.) shows a consistent upward trend, increasing from M = 3.30 (SD = 4.44) in 1º ESO to M = 5.47 (SD = 5.97) in 1º BACH. Meanwhile, the attempts needed to correctly answer the four final content reinforcement questions after completing all hypotheses (Afianz.) remain relatively stable, ranging between M = 1.10 and M = 1.22 across educational stages. Regarding completion rates, total completion ranges from 46.7% in 1º ESO to 71.4% in 1º BACH, while partial completion ranges from 61.1% in 1º ESO to 83.8% in 1º BACH.

**Table 2.** M and SD of app usage metrics

| Variable | 1º secondary education (1º ESO) | | 3º secondary education (3º ESO) | | 3º baccalaureate (1º BACH) | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD |
| H0 | 1.07 | 1.02 | 1.43 | 1.04 | 0.67 | 0.86 |
| H1 | 1.30 | 3.10 | 0.74 | 1.56 | 0.90 | 1.77 |
| H2 | 3.42 | 7.33 | 2.82 | 4.87 | 0.88 | 1.80 |
| H3 | 1.83 | 2.68 | 2.56 | 4.01 | 1.47 | 2.72 |
| H4 | 0.90 | 2.23 | 4.17 | 5.75 | 0.88 | 1.27 |
| VAR1 | 2.73 | 3.73 | 1.43 | 1.96 | 0.25 | 0.44 |
| VAR2 | 1.96 | 2.86 | 0.29 | 0.71 | 0.59 | 1.58 |
| VAR3 | 2.58 | 3.72 | 0.52 | 1.05 | 0.06 | 0.24 |
| VAR4 | 0.57 | 0.38 | 1.42 | 2.54 | 0.12 | 0.49 |
| SIM1 | 1.24 | 1.75 | 0.89 | 1.30 | 0.30 | 0.80 |
| SIM2 | 0.42 | 0.64 | 0.18 | 0.39 | 0.29 | 0.69 |
| SIM3 | 0.88 | 1.39 | 0.63 | 1.74 | 0.29 | 0.59 |
| SIM4 | 0.38 | 0.50 | 0.63 | 1.71 | 0.24 | 0.56 |
| Interp. | 3.30 | 4.44 | 4.35 | 3.68 | 5.47 | 5.97 |
| Afianz. | 1.10 | 0.85 | 1.22 | 0.90 | 1.20 | 0.86 |

Note. H0: Number of incorrect responses when identifying factors in hypothesis formulation; H1, H2, H3, and H4: Mistakes in answering interpretation questions related to the hypotheses; VAR1, VAR2, VAR3, and VAR4: Errors made when selecting independent, dependent, and control variables; SIM1, SIM2, SIM3, and SIM4: Errors committed during simulations of different hypotheses; Interp.: Number of attempts required to correctly answer five questions after testing a hypothesis; & Afianz.: Number of attempts needed to correctly answer the four final content reinforcement questions after completing all four hypotheses in an inquiry activity

**Table 3.** Effect sizes (Cohen's d) calculated for the significant results found by the Dunn test with Bonferroni correction

| Variable | Tested groups | p-value | Cohen's d |
|---|---|---|---|
| H1 | 3º ESO–1º BACH | < 0.05 | -0.10 |
| H3 | 3º ESO–1º BACH | < 0.05 | 0.32 |
| H2 | 3º ESO–1º BACH | < 0.05 | 0.53 |
| SIM1 | 3º ESO–1º BACH | < 0.05 | 0.55 |
| VAR2 | 1º ESO–1º BACH | < 0.05 | 0.59 |
| SIM1 | 1º ESO–1º BACH | < 0.05 | 0.69 |
| VAR3 | 1º ESO–3º ESO | < 0.01 | 0.75 |
| H4 | 3º ESO–1º BACH | < 0.01 | 0.79 |
| H0 | 3º ESO–1º BACH | < 0.01 | 0.80 |
| VAR2 | 1º ESO–3º ESO | < 0.01 | 0.80 |
| VAR1 | 3º ESO–1º BACH | < 0.01 | 0.83 |
| VAR1 | 1º ESO–1º BACH | < 0.01 | 0.93 |
| VAR3 | 1º ESO–1º BACH | < 0.01 | 0.96 |

Note. H0: Number of incorrect responses when identifying factors in hypothesis formulation; H1, H2, H3, and H4: Mistakes in answering interpretation questions related to the hypotheses; VAR1, VAR2, and VAR3: Errors made when selecting independent, dependent, and control variables; & SIM1: Errors committed during simulations of different hypotheses

Concerning the results of the hypothesis testing, statistically significant differences were identified using the Kruskal-Wallis test ($p < 0.05$). Specifically, significant differences were found in the variable related to the number of incorrect responses in hypothesis formulation (i.e., the number of times students failed to correctly identify the factors analyzed in the different hypotheses) between students in 3º ESO and 1º baccalaureate. For the variable SIM1, significant differences were observed between 1º baccalaureate and both 1º ESO and 3º ESO ($p < 0.05$). Significant differences were also found in the variables related to errors made when selecting independent, dependent, and control variables ($p < 0.05$). Specifically, for VAR1, differences were detected between 1º baccalaureate and both 1º ESO and 3º ESO. Regarding VAR2, significant differences were found between 3º ESO and 1º ESO, as well as between 1º baccalaureate and 1º ESO. Finally, for VAR3, significant differences were identified between 3º ESO and 1º ESO, and between 1º baccalaureate and 1º ESO. The analysis of effect sizes revealed that most differences were of moderate to large magnitude. Specifically, the largest effects were found for VAR3 (1º ESO–1º BACH) and VAR1 (1º ESO–1º BACH and 3º ESO–1º BACH; **Table 3**).

Similarly, H0 (3º ESO–1º BACH), H4 (3º ESO–1º BACH), and VAR2 (1º ESO–3º ESO) also showed large effects. Moderate effects were observed for H2 (3º ESO–1º BACH), SIM1 (3º ESO–1º BACH and 1º ESO–1º BACH), and VAR2 (1º ESO–1º BACH), while H3 (3º ESO–1º BACH) indicated a small effect. The only negligible effect was found for H1 (3º ESO–1º BACH), suggesting minimal difference between groups for that variable.

With respect to the CSUQ responses, the overall usability of IndagApp was positively evaluated by students, with the mean scores of the 16 CSUQ items ranging from 4.06 to 6.12 on a 7-point Likert scale (**Figure 1).** The item with the highest mean rating was item 16 ("Overall, I was satisfied with the educational application"), which scored M = 6.12 (SD = 1.23), followed closely by item 14 ("I enjoyed using this educational application") with M = 6.09 (SD = 1.19) and item 10 ("It is easy to find the information I need") with

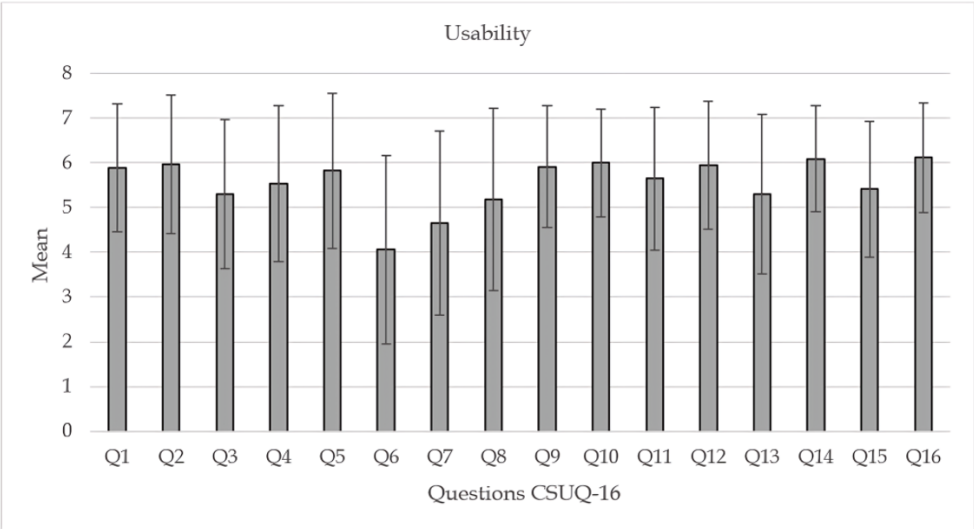


**Figure 1.** Single CSUQ scores (M ± SD): Scores: (1) strongly disagree, (2) largely disagree, (3) disagree, (4) neutral, (5) agree, (6) largely agree, & (7) strongly agree & Q = Question (Source: Authors' own elaboration)

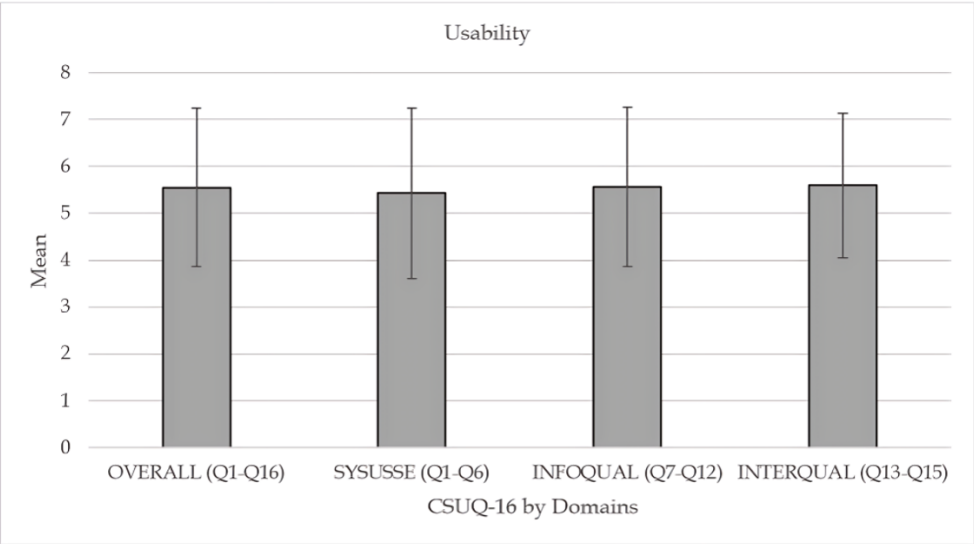


**Figure 2.** Single CSUQ scores (M ± SD): Scores: (1) strongly disagree, (2) largely disagree, (3) disagree, (4) neutral, (5) agree, (6) largely agree, & (7) strongly agree & Q = Question (Source: Authors' own elaboration)

M = 6.00 (SD = 1.21). These results suggest a high level of user satisfaction and a generally positive user experience in terms of navigation and engagement. In contrast, the lowest-rated items were item 6 ("I believe I became proficient quickly"), which received M = 4.06 (SD = 2.10), and item 7 ("The application displays error messages that clearly tell me how to solve problems"), with M = 4.65 (SD = 2.06). These lower scores point to areas for improvement, particularly regarding the initial learning curve and feedback system clarity. Despite these outliers, most items scored above 5, with relatively moderate variability (SDs between 1.21 and 2.10), indicating consistent positive evaluations across participants. The average scores and standard deviations for each CSUQ domain are as follows (**Figure 2**): overall, M = 5.5 (SD = 1.6); system usefulness, M = 5.4 (SD = 1.7); information quality, M = 5.6 (SD = 1.6); and interface quality, M = 5.6 (SD = 1.5).

Regarding the CSUQ responses, the non-parametric Kruskal-Wallis test did not reveal statistically significant differences among the domains ($p > 0.05$), nor were any significant differences found between the different educational levels analyzed (1º ESO, 3º ESO, and 1º baccalaureate).

## DISCUSSION

This study provides a comprehensive evaluation of IndagApp, a mobile application designed to support inquiry-based science education across different secondary education levels. The results provide valuable insights into how digital tools can foster the development of scientific inquiry skills, complementing and extending previous research in this field.

The general decreasing trend in errors and misconceptions observed from 1º ESO to 1º BACH aligns

with well-documented developmental trajectories in science education, where students progressively enhance their scientific reasoning and inquiry skills through structured instruction and repeated practice (Furtak et al., 2012; Lazonder & Harmsen, 2016). This is consistent with recent findings on scaffolded inquiry-based learning environments, which emphasize the importance of gradually transferring responsibility from teacher to student as learners become more competent (Arifin et al., 2025; Li & Fwu, 2026; Setyowati et al., 2023). The significant reductions in errors related to hypothesis formulation and variable identification suggest that IndagApp effectively supports the acquisition of foundational inquiry skills, a persistent challenge in science education.

However, the presence of non-linear trends in some error metrics (e.g., peaks in H0, H3, H4, VAR4, and SIM4) suggests that the development of inquiry skills does not necessarily follow a strictly linear trajectory across educational levels. One possible explanation is that certain tasks, particularly those requiring higher levels of abstraction or variable control, may impose greater cognitive demands on intermediate students (e.g., 3º ESO), who are transitioning from guided to more autonomous inquiry practices (Pedaste et al., 2015; Zacharia et al., 2015). In addition, curricular differences or variations in prior exposure to experimental design concepts might contribute to these fluctuations. It is also possible that motivational or contextual factors, such as task novelty or testing conditions, played a role in these temporary increases in error rates. This emphasizes the importance of adaptive scaffolding in educational technologies, which should be responsive to students' evolving needs and performance levels. Incorporating real-time feedback and intelligent, personalized hints has been shown to support learners' conceptual understanding and procedural competence in inquiry-based learning environments (de Jong et al., 2021; Rúa Martínez et al., 2024).

The increasing number of attempts required to answer interpretation questions correctly, especially at higher educational levels, may reflect deeper engagement rather than lack of comprehension. Older students are likely to approach inquiry tasks with greater critical thinking and self-regulation, resulting in more reflective problem solving and iterative attempts to refine their understanding (Panadero, 2017). This is consistent with recent findings indicating that inquiry-based learning promotes higher-order cognitive skills, such as hypothesis evaluation and data interpretation (Chen & Chen, 2021; Khalaf et al., 2025; Ribeirinha et al., 2024). The relatively stable scores on content reinforcement questions suggest that IndagApp effectively supports conceptual consolidation, aligning with research showing that well-designed digital learning tools can enhance long-term knowledge retention (de Jong et al., 2021).

Regarding usability, the high CSUQ scores and lack of significant differences across educational levels are promising, indicating that IndagApp's interface and functionality meet diverse learners' needs effectively. Similar CSUQ scores were reported for the app following a usability evaluation conducted with elementary school students aged 9-12 (Yánez-Pérez et al., 2024c). This finding aligns with recent studies emphasizing usability as a critical factor for the adoption and sustained use of educational technology (Criollo-C et al., 2025; Toma & Greca, 2018). However, the relatively lower scores on some items highlight potential areas for improvement, such as information clarity and interface responsiveness, which are commonly cited barriers in mobile learning environments (Hajesmaeel-Gohari et al., 2022). Addressing these concerns will enhance user satisfaction and maximize the pedagogical impact of the app.

The statistically significant differences found in app usage metrics between educational levels further validate the notion that cognitive and experiential factors influence inquiry performance. These findings align with earlier studies showing that the development of inquiry skills is a gradual process, requiring instructional supports that are thoughtfully structured and adapt as students gain experience and knowledge (Quintana et al., 2004). The absence of significant differences in usability perceptions suggests that while learning challenges vary, the app's design maintains broad accessibility, a key feature for scalable educational interventions (Sauro & Lewis, 2016).

The current findings position IndagApp as a valuable resource aligned with the competencies promoted by the Spanish educational reform (LOMLOE, 2020), bridging theoretical knowledge and practical inquiry in a digital format. Similar initiatives, such as the science learning games (Wang et al., 2025) and virtual lab environments (Navarro et al., 2024), have demonstrated the benefits of combining inquiry pedagogy with interactive technology. IndagApp's unique contribution lies in its layered inquiry levels and detailed feedback mechanisms, which appear to support differentiated learning paths effectively.

## Educational Implications

The findings of this study have important implications for enhancing inquiry-based science education through digital tools such as IndagApp. The observed improvements in student performance across educational stages highlight the necessity of providing age-appropriate scaffolding that supports gradual development of inquiry skills, from hypothesis formulation to data interpretation. This suggests that educators should integrate apps like IndagApp to complement classroom instruction by facilitating structured and guided inquiry experiences tailored to students' developmental levels. Additionally, the

varying patterns of errors and attempts indicate the potential benefits of incorporating adaptive feedback mechanisms within educational apps, enabling personalized support that addresses individual learning challenges and promotes metacognitive reflection. The increasing engagement and persistence reflected in repeated attempts suggest that such tools can motivate students to deepen their scientific reasoning and problem-solving skills. Furthermore, the high usability ratings affirm that well-designed mobile applications can be accessible and user-friendly for diverse learners, emphasizing the importance of combining pedagogical effectiveness with intuitive interfaces to reduce barriers to adoption of technology. To fully leverage the educational value of IndagApp, it is essential that its use be embedded within broader instructional strategies, supported by teacher training programs that enhance educators' ability to implement inquiry-based digital resources effectively. Finally, these results underscore the relevance of integrating digital inquiry tools within curriculum development and educational policy frameworks, such as Spain's LOMLOE, which advocate for competency-based, student-centered learning, ensuring equitable access to quality science education through innovative technological resources.

### Limitations and Future Research

This study presents several limitations that should be acknowledged when interpreting the findings. First, the research was conducted with a relatively small sample drawn from a single public secondary school, which may limit the generalizability of the results to broader educational contexts. Second, the study employed a cross-sectional design, preventing the establishment of causal relationships or the observation of changes in inquiry skills over time. Additionally, the absence of a control group restricts the ability to isolate the specific contribution of IndagApp to students' learning outcomes, as other contextual factors might have influenced performance.

Future research should explore longitudinal effects to track skill acquisition over time and investigate integration strategies with classroom instruction to maximize learning gains. Additionally, qualitative studies examining student and teacher experiences can provide deeper insights into usability and pedagogical alignment. Finally, expanding evaluations to diverse educational contexts and student populations will enhance the generalizability of findings and inform further app refinement.

## CONCLUSIONS

This study demonstrates that IndagApp is an effective and usable digital tool for supporting inquiry-based science education across multiple secondary education levels. The analysis of app usage metrics revealed a general improvement in students' inquiry skills, reflected by a decline in errors and increased engagement from early secondary education to baccalaureate. These results suggest that IndagApp provides appropriate scaffolding that facilitates the progressive development of critical scientific competencies such as hypothesis formulation, variable identification, and data interpretation. The usability evaluation confirmed that the app is well-received by students, indicating its potential for wide adoption in educational contexts. Although some variables exhibited fluctuating trends, the overall positive outcomes underscore the value of incorporating technology-enhanced inquiry learning within science curricula. Furthermore, the absence of significant differences in usability perceptions across educational stages highlights the app's accessibility and user-friendliness for diverse learners. Future research should explore long-term impacts on learning outcomes and investigate how integration with classroom teaching can be optimized. These findings contribute to the growing body of evidence supporting digital tools as catalysts for improving science education and aligning instructional practices with modern pedagogical frameworks such as LOMLOE.

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