EcoView: An AI-powered App for Enhancing Biological Inspired Design in Pre-College Engineering Education (Fundamental Research)

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EcoView: An AI-powered App for Enhancing Biologically Inspired Design in K-12 Engineering Education (Fundamental Research)

Abstract

This pilot study examines EcoView, an AI-enhanced mobile app designed to support K–12 students in Biologically Inspired Design (BID) using the Structure–Function–Mechanism (SFM) framework. EcoView addresses challenges students face in understanding complex biological concepts by analyzing user-submitted animal images and generating educational insights that link biology and engineering. Its three-part design: Educate, Explore, Extrapolate, combines a curated knowledge base, AI-driven image analysis, and interactive features such as quizzes to scaffold learning. A mixed-methods evaluation using surveys and interviews assessed usability, engagement, and educational impact. Results show that students found the app intuitive and motivating, with AI supporting conceptual understanding, particularly for learners with limited prior knowledge. Overall, EcoView demonstrates the potential of AI-driven educational tools to make complex interdisciplinary topics like BID more accessible, personalized, and engaging for K–12 STEM learners.

***Keywords**: Artificial Intelligence; Biologically Inspired Design; Engineering; App*

Introduction

Biologically Inspired Design (BID), or biomimicry, has recently gained traction in K–12 education as an effective way to teach STEM and engineering concepts [1–4]. By studying evolved biological strategies, students explore efficient, sustainable solutions through tangible, nature-based examples [5]. Central to BID instruction is the Structure–Function–Mechanism (SFM) framework, which helps students analyze biological features by form, purpose, and operation [6]. Research shows that SFM-based BID activities strengthen connections between biological structures and engineered functions, enhancing both biological understanding and engineering reasoning [7].

However, students often struggle with complex biological systems due to multiscale interactions, abstract mechanisms, and high cognitive load [8]. Digital tools, such as simulations, apps, multimedia, and virtual labs, can address these challenges by enabling hands-on exploration of scientific and engineering principles, deepening understanding, and boosting STEM interest [9]. This paper examines the development and evaluation of a BID app for K–12 education highlighting how technology can support BID pedagogy. It emphasizes that maximizing BID's potential requires a sustained synergy among biological knowledge, technological innovation, and educational practice [9].

Background

Biologically Inspired Design in K-12

Biologically Inspired Design (BID) engages students by drawing inspiration from nature's evolved strategies to solve human problems, introducing them to core engineering principles in practical, hands-on ways [5,11]. By connecting structure, function, and mechanism (SFM), BID enables students to analyze how biological systems achieve specific roles, fostering understanding of essential engineering concepts such as problem-solving, optimization, efficiency, and sustainability [12–13,16]. This approach is particularly effective for learners with limited prior exposure to engineering, allowing them to grasp design thinking and systems analysis through real-world examples rather than abstract theory [5].

Integrating BID in K–12 classrooms align with STEM education priorities, promoting systems thinking and interdisciplinary connections between biology, design, and environmental responsibility [14]. Educators increasingly adopt BID to enhance engagement in STEM, often using the SFM framework as a key instructional tool [1–4,15]. However, traditional instruction alone can make SFM concepts difficult for students to grasp, highlighting the need for supportive educational technologies [16].

The Role of Technology in BID Learning

Technology offers powerful ways to connect observation and conceptual understanding in BID. Tools such as image recognition apps allow students to identify organisms and link their structures to functional roles in real time, making abstract SFM relationships tangible [17]. Interactive simulations, virtual labs, educational apps, and engineering-focused tools like CAD software or robotics kits provide hands-on opportunities to explore complex systems, prototype designs, and engage in iterative problem-solving [18–23]. These resources enhance learning by concretizing abstract concepts, supporting collaboration, and fostering creativity.

Emerging technologies, including augmented reality (AR) and AI-driven tutors, further enrich BID education. AR enables immersive visualization of biological structures and mechanisms, improving spatial understanding and engagement [28–29], while AI tutors offer immediate, personalized feedback to reinforce conceptual understanding and inquiry-based problem solving [30]. Digital notebooks and similar tools support the organization and synthesis of SFM information, promoting reflection and iterative learning [27]. Integrating these technologies into STEM curricula provides flexible, scalable, and engaging experiences that strengthen interdisciplinary thinking, deepen understanding of biology and engineering, and prepare students for 21st-century STEM careers, particularly in areas like BID [26].

Theoretical Framework: Structure-Function-Mechanism

This study is grounded in the Structure–Function–Mechanism (SFM) Framework, developed by Helms et al. [6] as an evolution of the Structure–Behavior–Function (SBF) model [7, 34]. Unlike SBF, SFM emphasizes mechanisms—the internal processes driving biological functions, enabling students to uncover principles that inform innovative engineering solutions. Aligned with the Next Generation Science Standards (NGSS), SFM encourages active engagement with natural systems, fostering ecological understanding [6, 35–36].

BID leverages SFM's integration of structure, function, and mechanism to reflect how biological systems achieve optimal performance through tightly coupled relationships [32]. By providing a shared language for interdisciplinary collaboration, SFM bridges biological complexity with engineering rigor, supporting scalable and testable solutions [6, 31, 32–35]. Although mapping complex biological systems to engineering principles can be challenging [37–38], AI tools can scaffold learning by visualizing structure–function relationships, guiding system decomposition, and delivering tailored feedback [39–40].

Moreover, BID requires a dual understanding: mastery of the engineering problem and comprehension of relevant biological systems that can inform solutions [31–32]. This perspective involves systematically analyzing biological structures and functions to identify elements transferable to engineering contexts, mirroring how engineers decompose complex systems into structural and functional components [33]. The SFM framework underpins the design of innovative engineering systems across domains. Biological structures provide hierarchical models, functions define performance goals, and mechanisms enable adaptability and resilience [6, 33, 35]. Leveraging these interrelated dimensions remains essential for advancing sustainable, adaptive, and effective technologies [31, 36].

Purpose and Research Questions

This study evaluates the BID app, a digital tool developed to teach students about biologically inspired design (BID) and support their design process by guiding exploration of structure, function, and mechanism. The app aims to help students apply BID principles by connecting biological inspiration with engineering solutions. This research investigates the following questions: (1) How do students describe their experiences using the BID app to explore and deepen their understanding of biological systems? (2) What challenges or limitations do students encounter when using the BID app, and how do these affect its overall effectiveness?

Methods

Research Design

A mixed-method convergent parallel design (QUANT→qual) was employed to address the research questions. A mixed method design is advantageous when the research seeks to address questions such as 'how' and 'what' holistically within a specific context or situation [41]. Therefore, in this study, a mixed-methods convergent parallel design was employed to provide a comprehensive understanding of students' perceptions of and experiences with the BID app, including its design features and usability. The qualitative and quantitative methods were implemented concurrently within the same phase of the research process; however, the analyses of the two components were conducted independently [41].

Participants and setting

The participants in this study were 12th-grade and first-year undergraduate students (n=17) aged 18 or older. Participants were recruited via purposive convenience sampling through partnerships with the developers' local high school and undergraduate programs that offer engineering or STEM-related coursework. The 17 participants represented diverse racial, academic, and educational backgrounds (see Table 1). A majority (76%) reported having taken at least one engineering course, whereas 24% reported no prior engineering coursework. Although all students were asked whether they would be willing to be interviewed, only 5 of 17 agreed to participate. Prior to participation, informed consent was obtained from all participants aged 18 or older. Of the students interviewed, three were male, and two were female. Prior to data collection, participants were informed that their participation was voluntary, that they could withdraw at any time without penalty, and that all responses would be kept confidential and reported in aggregate.

Table 1. Participant Demographics

Category	Sub-Category	N	Percentage
Race	White	8	47%
	African American	1	6%
	Hispanic	1	6%
	Asian	4	23%
	Mixed	3	18%
Grade	12th	13	76%
	Undergraduate	4	24%
Gender	Male	11	65%
	Female	6	35%
Have you taken any engineering courses?	Yes	13	76%
	No	4	24%

Context: EcoView Application

A mobile application was developed to support K–12 students in learning about bio-inspired design by analyzing animal photographs and delivering tailored educational content. The app integrates artificial intelligence (AI) to interpret animal imagery and provide structured, informative responses grounded in design principles inspired by nature. The project was approached collaboratively, with one team member focusing on backend development and the other on user interface and experience design. This division of labor facilitated a targeted, iterative design process that addressed both technical functionality and pedagogical usability.

Backend Development and Technical Design. The app's technical foundation leveraged AI as the primary tool for analyzing visual input. To inform the backend architecture, the development process began with an exploration of existing AI capabilities using the ChatGPT

API. This initial research phase guided the logic and structure of the system before any code was implemented.

The backend framework was prototyped in Xcode and subsequently migrated to a cloud-based platform (Replit.com) to enable more flexible development. The first iteration included basic functionality, such as image input and text output. Over time, the backend was refined to enhance the AI's responsiveness and its ability to handle follow-up queries. This evolution was critical in aligning the app's capabilities with the learning goals of bio-inspired design education. Due to limitations encountered during code integration with the OpenAI platform, the AI functionality was ultimately transitioned to Google's Gemini API to ensure stability and compatibility within the app's larger codebase.

Frontend Design and User Experience. Concurrently, the frontend design focused on ensuring accessibility and engagement for users ranging from sixth to twelfth grade. A user centered design framework was adopted, with emphasis on clarity, simplicity, and educational value. The application was structured into three main sections, Educate, Explore, and Extrapolate (See Figures 1-3), each serving a distinct function in the learning process:

- **Educate**: Provides access to a database of previously analyzed animals, allowing students to review and reinforce their understanding of bio-inspired design principles.
- **Explore**: Enables users to upload or capture new animal photographs, which are then analyzed using the AI model.
- **Extrapolate**: Presents AI-generated interpretations of the submitted images, highlighting how animal features might inform design innovations.

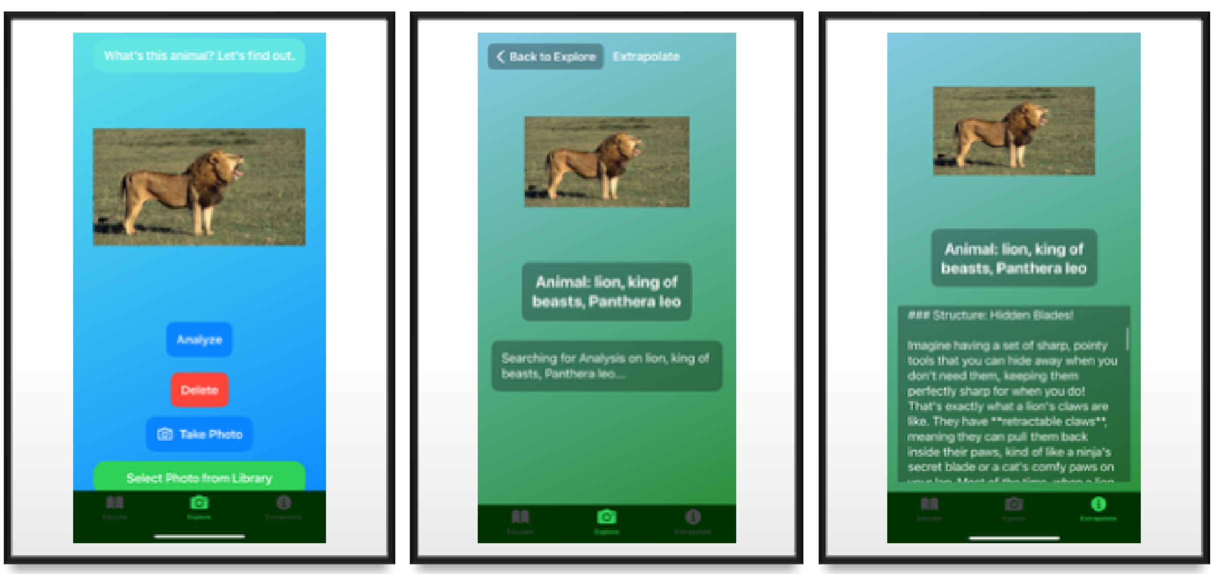

Figure 1. Explore feature

Figure 2. Explore feature after image captured or uploaded

Figure 3. Extrapolate feature

Figures 1-3. BID Application structures and features

To further enhance user engagement and knowledge retention, a quiz feature was embedded within the Educate section (See Figure 4-6 below). This allowed students to test their understanding of animal adaptations and their applications in design.

A nature-inspired visual theme featuring gradient backgrounds in green, blue, and purple was selected to evoke a calming atmosphere, aligning with the app's ecological focus (See Figures 16). The aesthetic design was purposefully kept intuitive to ensure usability without sacrificing content depth.

Figure 4. Educate feature

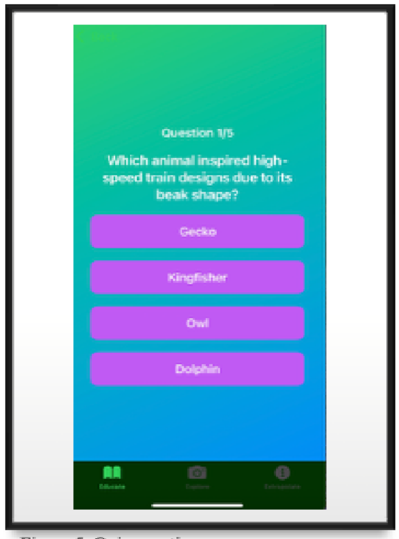

Figure 5. Quiz question

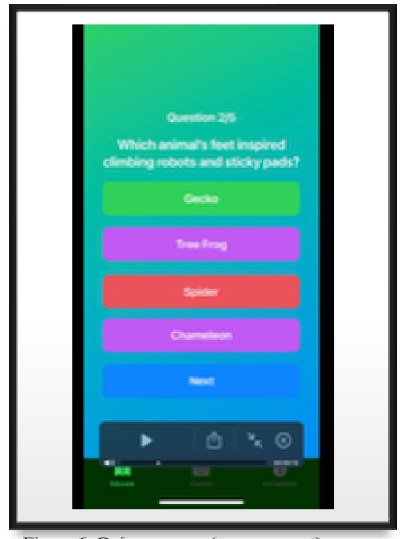

Figure 6. Quiz response (green correct)

Figures 4 -6. BID Application Educate feature s

In response to initial user testing and feedback, the application's functionality was systematically enhanced, and several key revisions were implemented to better meet the needs of its target audience. Early evaluations revealed opportunities to optimize both the educational value and user interface, prompting the development team to introduce new features and adjust existing components for greater clarity and accessibility. For example, the quiz feature in the Educate section was redesigned so that when a user selects an answer, the chosen option changes color—green for correct and red for incorrect—while always displaying the correct answer to provide immediate and clear feedback (See Figures 5 & 6). This approach ensures students can quickly understand their mistakes and reinforces learning outcomes.

The interface was refined to streamline navigation and present information in a more intuitive manner, ensuring that students could easily access core features without unnecessary complexity. For instance, terminology in the Educate section was updated based on user confusion over "What is BID?" now, the full term "What is Biologically-Inspired Design" is shown along with an explanation, making it easier for users with limited field knowledge to understand the app's core purpose (See Figures 7 & 8). Additionally, accessibility improvements were incorporated, such as clearer visual cues and simplified layouts, to accommodate a wider range of learners, including those with varying levels of prior knowledge and differing learning styles. These iterative updates collectively contributed to a more robust, user-centered application that effectively supports the exploration of biologically inspired design concepts.

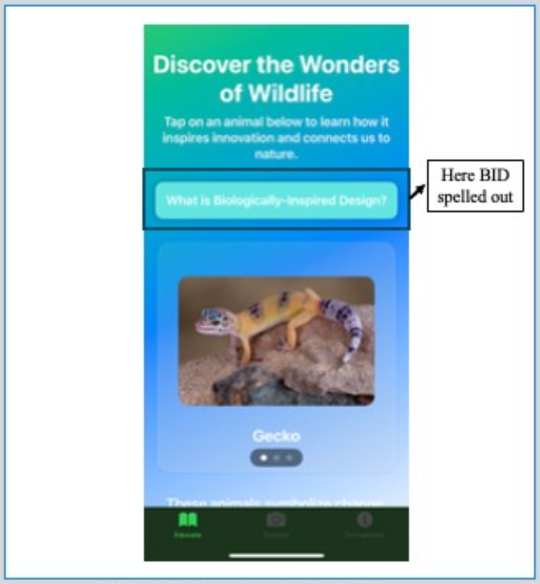

Figure 7. Educate feature BID spelled out

Figure 8: BID explained in detail with examples

Figures 7-8. BID Application revised Educate features

Data Sources

The data sources for this pilot study included a survey and semi-structured interviews with students. The survey consisted of 14 five-point Likert-scale items, ranging from 1 (strongly disagree) to 5 (strongly agree). Students responded to items regarding their overall experience with the app, engagement and interaction, accessibility, and technical issues. The items were based on previously validated instruments commonly used in educational technology and user experience research (e.g., 42-44) and were adapted to fit the specific context of the app in question. The survey was designed with emphasis on clarity and relevance, following recommendations by DeVellis [44] to ensure construct validity and response reliability (See Table 2 for sample items for each construct).

Table 2. Sample Items for BID App

Construct	Item (s)
General Experience	• The app was easy to use. • I understood what I was supposed to do in each part of the app. • It was easy to move between different screens and activities. • I liked the way the app looked (colors, design, layout).
Engagement and Interaction	• The app kept me interested • I learned something new about nature or design from the app.

	• This app helped me understand concepts essential to engineering and design.
Accessibility and Use	• I could read all the text and see the images clearly. • The app worked well without freezing or crashing. • I could use the app on my device without problems.

This was followed by semi-structured interviews, designed to provide deeper insights into students' perceptions and to complement the quantitative findings with qualitative data. Interview questions focused on themes such as perceived usefulness, ease of use, and educational effectiveness, particularly in the context of learning BID. The combination of surveys and interviews supports methodological triangulation, enhancing the study's credibility and enabling a more comprehensive understanding of the user experience [41].

Data Analysis

The survey data was analyzed quantitatively using descriptive statistics (i.e., frequencies and percentages) to summarize participants' responses [45]. This provided a clear overview of how participants rated various aspects of their experience with the app, including Overall Experience, Engagement and Interaction, and Accessibility and Technical Issues. The analysis highlighted the distribution of responses for each item, providing insight into areas of consensus (e.g., high levels of agreement) and items with more mixed feedback. This method was useful for identifying overall trends in student perceptions and for pinpointing specific strengths and areas for improvement in the app.

A thematic analysis, as outlined by Braun and Clarke [46] in their six-phase framework, was conducted on the semi-structured interview transcripts because this approach is recommended for descriptive qualitative research and is well-suited to capturing participants' perspectives. Although the framework is frequently characterized as linear, our methodology was iterative and reflective, encompassing regular revisits across phases [46-47] and was complemented by comprehensive discussions among coders to develop meaningful themes. Discrepancies were resolved through collaborative dialogues among multiple coders across various stages. Three major themes emerged from the data: *Engagement Through Interactive Features, Content Complexity and Age Appropriateness, and Support for Conceptual Understanding* (see Table 3 for definitions of the major themes). The study findings are organized around themes that emerged from the data, as highlighted. To protect participant anonymity, participants' names are replaced with pseudonyms (e.g., S1, S2, etc.).

Table 3. Major themes and definitions

Theme	Definition
Engagement Through Interactive Features	This theme refers to the ways in which interactive elements, such as quizzes, images, and feedback mechanisms enhance user engagement and motivation within the educational app experience.

Content Complexity and Age Appropriateness	This theme captures the user's perceptions of how well the content complexity aligns with the cognitive and developmental needs of the intended audience, particularly younger users.
Support for Conceptual Understanding	This theme explores how the app facilitated the user's understanding of the core concept, biologically inspired design (BID), particularly in the context of limited prior knowledge.

Findings

Overall, the quantitative findings revealed that most users found the app straightforward to navigate, with its interface and guidance supporting task completion. While most appreciated the clarity of the instructions, some experienced confusion and suggested clearer support. The visual design was generally well received, though some were neutral. Engagement levels were positive, but some participants remained indifferent or disengaged, suggesting the need for more interactive elements. The app was effective for gaining new knowledge and was useful in STEM learning contexts, with a strong willingness to use it in classrooms. However, its impact on deeper conceptual understanding and support for advanced learning was moderate, suggesting further improvement.

Experience with the App

The data indicate that users generally had a positive overall experience with the app, particularly with usability and navigation (See Figure 9). A substantial majority of participants (88%) agreed that the app was easy to use, highlighting the app's intuitive interface and well-designed user experience. Moreover, 88% of users reported understanding their expected tasks in each part of the app, suggesting that the app's structure and task design provided clear guidance and helped users remain oriented throughout their interactions. The ease of navigation was also highly rated, with 88% affirming that moving between different screens and activities was straightforward. This suggests that the app's flow was logical and well-organized, minimizing cognitive load and frustration often associated with poorly designed interfaces

Despite these strengths, instructional clarity remained an area for improvement. While 71% agreed that instructions within the app were clear, a significant minority (12%) disagreed, and 18% were neutral. This split indicates that although most users could follow the guidance provided, a notable subset experienced confusion or ambiguity in understanding the instructions. Such variability in perceived instructional clarity indicates a need to refine the instructional text or to incorporate additional scaffolding, such as tooltips, step-by-step walkthroughs, or multimedia instructions to support diverse learning preferences and reduce misinterpretation. Visual design elements, including colors, layout, and overall aesthetics, were liked by 76% of respondents, whereas 24% were neutral. Although this reflects generally positive feedback, it suggests opportunities to enhance the app's visual appeal, which could further contribute to a more engaging and inviting user experience.

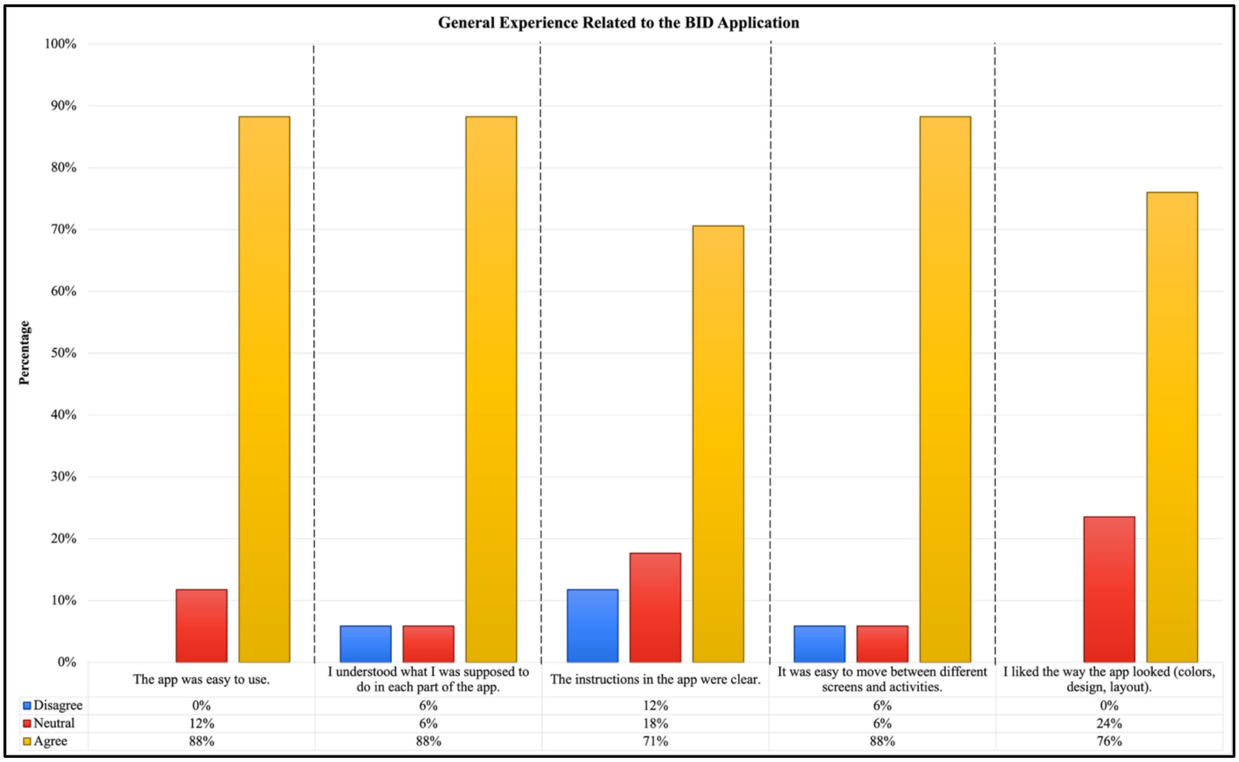

Figure 9. Students' general experience related to the bid application

Engagement and Interaction

User engagement and interactive experience present a more nuanced picture. Although a majority (71%) felt that the app kept them interested, the presence of 6% disagreement and a sizeable 24% neutral response indicates that the app's ability to sustain engagement over time is moderate rather than robust. This suggests that, while initial interaction is generally appealing, the app may benefit from incorporating additional interactive or gamified elements, such as challenges, rewards, or adaptive difficulty, to better capture and maintain user attention (see Figure 10).

From an educational standpoint, the app delivered new knowledge. A strong 88% of participants agreed that they learned something new about nature or design, supporting the app's value as a learning tool for introducing concepts relevant to these fields. Furthermore, 71% perceived the app as useful in engineering or science classes, and 94% expressed willingness to use it in a classroom project or lesson. These findings highlight the app's perceived relevance and potential integration into formal educational settings.

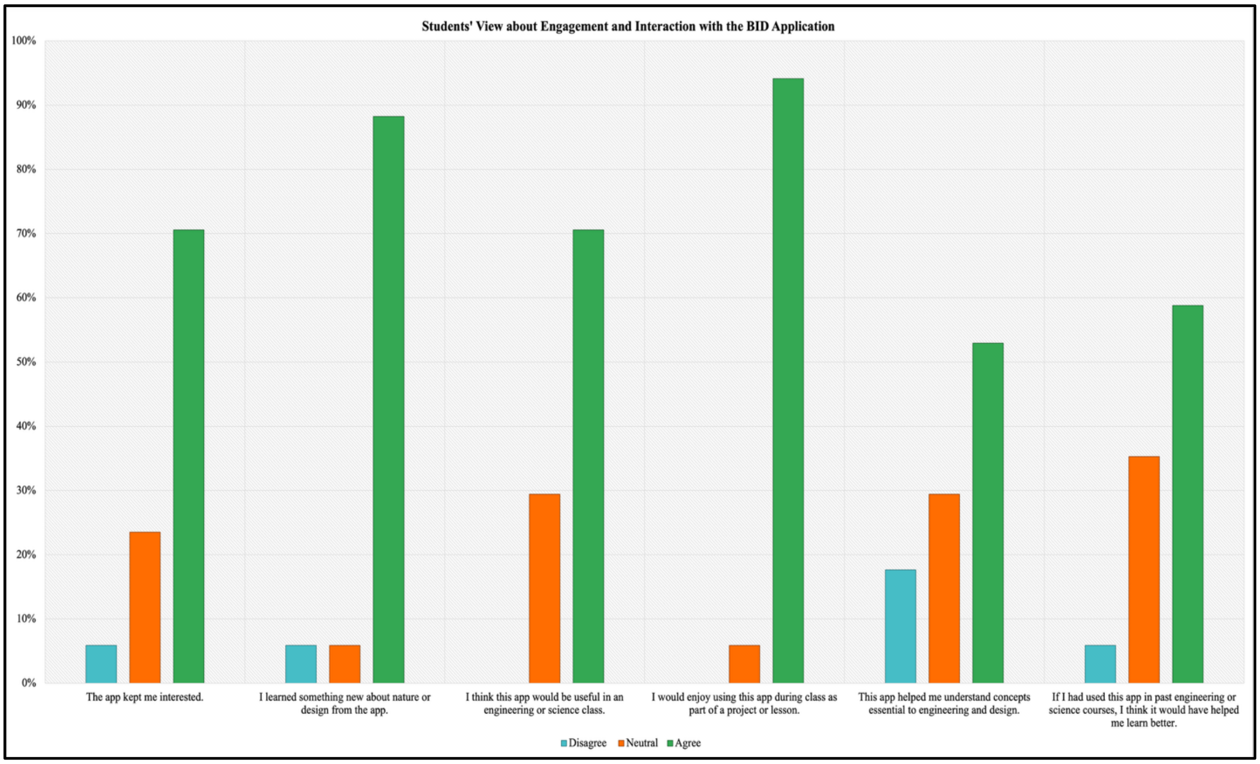

Figure 10. Students' views about engagement and interaction with the BID app

However, the app's effectiveness in fostering deeper conceptual understanding was less pronounced. Only 53% agreed that the app helped them understand essential engineering and design concepts, while 18% disagreed and 23% were neutral. This suggests that while the app is effective for surface-level learning and engagement, it may not fully support higher-order cognitive processes required for deep comprehension and application. Additionally, when asked if the app would have helped them learn better in previous courses, a little more than half (59%) responded affirmatively. This moderate endorsement indicates that, although the app is perceived as beneficial, it may require enhancements, such as more complex problem-solving activities, real-world simulations, or integrated assessments, to enhance its pedagogical impact on advanced learning.

Accessibility and Technical Issues

Accessibility and technical reliability were generally viewed positively, but some challenges remain. A notable 94% of participants reported being able to clearly read all text and see images, indicating that the app meets essential visual accessibility standards. This is critical for ensuring that users can engage fully with the content without being hindered by poor readability or unclear visuals (Figure 11).

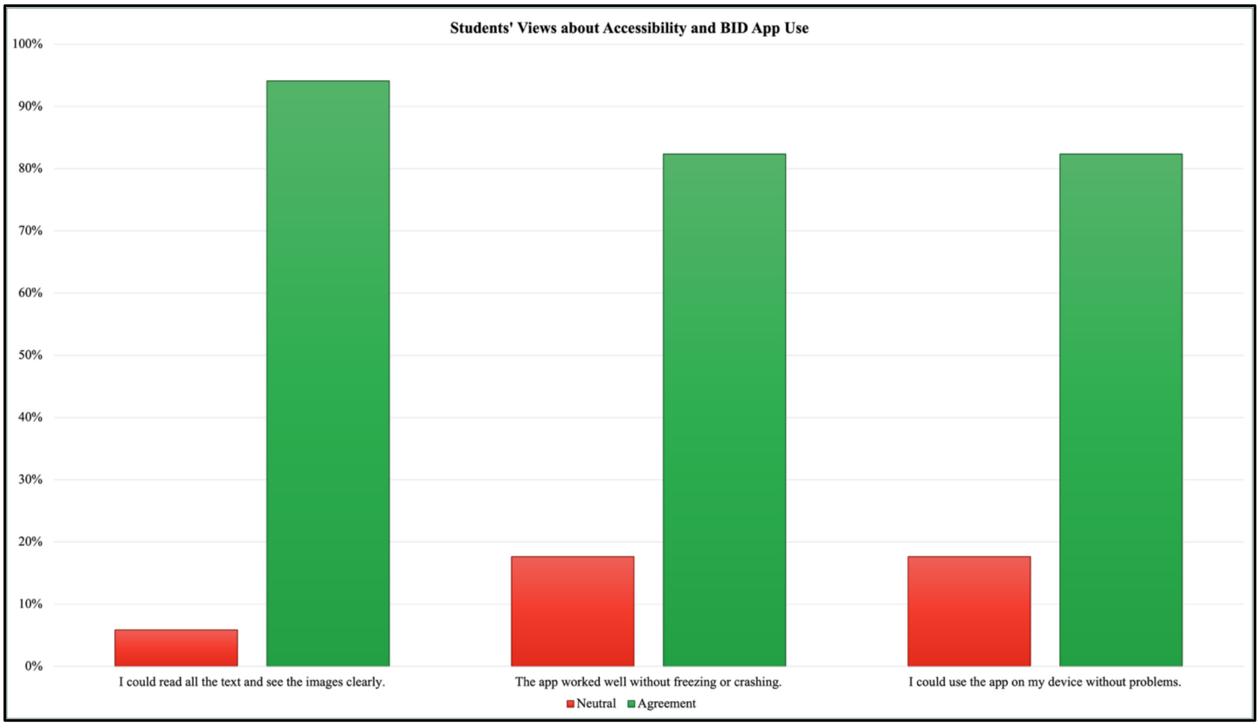

Figure 11. Students' views about the BID app's accessibility and use.

In terms of technical performance, 82% of respondents reported that the app ran smoothly without freezing or crashing, suggesting a stable and reliable software platform for most users. Nevertheless, device compatibility emerged as a potential concern. While 82% reported they could use the app on their devices without problems, 18% were neutral, suggesting that a significant portion of users may have encountered minor issues or uncertainties related to device performance or app responsiveness. This could be due to variations in hardware specifications, operating systems, or network conditions. Addressing these technical and compatibility issues is essential for broadening access and ensuring equitable usability across diverse user groups.

Qualitative Findings

The qualitative analysis revealed three central themes in students' perceptions of the BID app: high levels of engagement fostered by its interactive features, the suitability of the content for younger learners, and the app's effectiveness in supporting conceptual understanding. Together, these findings suggest that the BID app not only captures students' interest but also provides developmentally appropriate scaffolding that enhances meaningful learning of core concepts, corroborating the quantitative findings. These themes are discussed below.

Theme 1: Engagement Through Interactive Features

This theme refers to the ways in which interactive elements, such as quizzes, images, and feedback mechanisms, enhance user engagement and motivation within the educational app experience.

One of the most prominent themes emerging from the interview was the user's enthusiastic response to the app's interactive features, particularly the quiz function. The participant emphasized that the quiz, which was incorporated in the app to assess their understanding, not only made the experience enjoyable but also helped them identify what they didn't know, motivating them to explore more information. As one student stated, *"It showed me whatever I didn't know, which was fun"* (S2), highlighting the quiz's dual role as both an assessment tool and a prompt for further learning.

Additionally, the ability to integrate images added another layer of engagement, as multiple students (S1, S4, S5) asserted. Specifically, one claimed that *"I could put an image of the animal and learn more about the animal to do better on the quiz"* (S5), referring to the ability to learn about multiple organisms by simply uploading the images, then proceeding to the quiz to test one's knowledge.

These responses suggest that features that combine playfulness with purpose, such as feedback loops and media integration, can effectively foster active learning. The repeated expressions of satisfaction, by all students, for instance, *"That's good*" (S1), *That's good"*(S5), and "*You're doing a good job at teaching me"* (S2), reinforce the idea that the app successfully captured the user's attention and supported an intrinsically rewarding learning experience. Overall, this theme highlights the importance of interactive learning design in fostering user engagement.

Theme 2: Content Complexity and Age Appropriateness

This theme captures the user's perceptions of how well the content complexity aligns with the cognitive and developmental needs of the intended audience, particularly younger users. While the app was praised for being easy to navigate, the participant raised concerns about the level of detail in some of the content, especially when considering younger users. As one student asserted, *"If the app is geared towards a younger audience, maybe it doesn't need as much information"* (S4), suggesting that although depth is valuable, too much information might overwhelm or confuse certain users. The student was careful not to criticize the content harshly but hinted at the need for further simplification, as he further went on to state*, "I don't want to say dumb down, but simplify,"* and added, *"Even though it is pretty simple already, but a little bit simpler"* (S5). These comments highlight the tension between delivering rich, meaningful content and ensuring its developmental appropriateness.

Furthermore, another student was dissatisfied with the *"hashtags"* and considered them unappealing and confusing. The student stated, There were also some parts where I saw, like, hashtags, which made the app confusing" (S1). This also suggests that some formatting or interface elements may have seemed out of place or confusing. Although several participants reassured that *"nothing was hard to use"* (S1, S4, S3), their reflections on content complexity reveal a need for adaptive content design that aligns with the varying levels of understanding and attention spans across age groups. This theme highlights the importance of striking a balance between educational depth and accessibility.

Theme 3: Support for Conceptual Understanding

This theme explores how the app facilitates the user's understanding of the core concept of biologically inspired design (BID), particularly in the context of limited prior knowledge. The final theme highlights the app's role in fostering conceptual learning, particularly in the context of biologically inspired design. Many students openly admitted to having minimal prior exposure to the concept, as one student claimed, "My understanding of biological design... is very limited" (S3). Despite this, they felt that the app significantly enhanced their understanding, as another student pointed out, *"What I didn't know, this app enforced it a lot, I'd say"* (S1). These statements illustrate the app's effectiveness in scaffolding the acquisition of new knowledge and promoting meaningful learning among users with low baseline knowledge.

Moreover, the students also described the learning process as cumulative and informative. Student two claimed, *"Pretty much every animal that I looked up or that I saw, I learned more information"* (S2). This suggests that the app's structure encouraged discovery-based learning, allowing users to build conceptual knowledge through repeated exposure to diverse examples. The participant's reflective tone further indicates a developing ability to articulate and apply the concept. Overall, this theme underscores the app's value as a tool for introducing and reinforcing complex scientific ideas through accessible, example-rich content and exploratory learning pathways, such as quizzes.

Discussion

The findings from this study provide a comprehensive picture of students' experiences with the EcoView BID app, highlighting its strengths in usability, engagement, and introductory learning, while also revealing areas for improvement related to instructional clarity and deeper conceptual understanding. Taken together, the quantitative and qualitative results suggest that the app is well positioned as an accessible and engaging entry point to biologically inspired design, particularly for novice and younger learners, but would benefit from enhanced scaffolding and greater instructional depth to support higher-order learning outcomes.

Quantitative results for ease of use, navigation, and task clarity indicate that the BID app follows sound usability principles, minimizing extraneous cognitive load and allowing users to focus on learning [48]. Qualitative feedback, such as "nothing was hard to use," reinforces that the interface aligns with human-computer interaction guidelines emphasizing clarity, consistency, and intuitive design [49]. However, variability in perceptions of instructional clarity suggests that some learners may require additional scaffolding. Prior research highlights the importance of examples, prompts, and just-in-time feedback to support diverse prior knowledge and learning preferences [50]. Enhancing these supports could improve equity and reduce ambiguity during task completion.

Engagement was a key strength of the BID app, driven by interactive features such as quizzes, image uploads, and feedback mechanisms. These elements enhanced motivation and curiosity driven, exploratory learning, consistent with constructivist and inquiry-based STEM approaches

[51–53]. Research shows engagement is strongest when interactive features include meaningful challenges, adaptive difficulty, and learner choice [43]. Incorporating gamified or problem-based tasks linked to engineering decision-making could further sustain attention and deepen involvement.

The app was generally perceived as effective for acquiring new knowledge and suitable for STEM classrooms, supporting introductory and surface-level learning, especially for students with limited prior exposure to BID. Qualitative reflections indicated cumulative learning through example-rich exploration, a strategy known to foster conceptual growth in novice learners [31–32]. However, ratings for deeper conceptual understanding were more modest; only about half of participants felt the app supported essential engineering and design concepts. This suggests that while the app effectively introduces BID, it may not fully support abstraction, transfer, or application, highlighting the need for explicit connections between structure, function, and mechanism to promote robust, higher-order learning [31–32].

Overall, the findings suggest that the BID AI-powered app functions effectively as an engaging, accessible introduction to BID and holds strong potential for classroom integration. To enhance its impact on deeper learning, future iterations should emphasize explicit conceptual connections, richer problem-solving tasks, and adaptive scaffolding aligned with learners' prior knowledge. By strengthening these elements, the app could more fully support the development of conceptual understanding central to biology–engineering integration and design-based STEM education.

Limitation

The study results are meaningful for the development of a future AI-powered app. However, several limitations should be considered when interpreting the study's findings. First, the sample size was small and included students with varied educational backgrounds and prior STEM exposure, limiting the generalizability of results [41]. Trends in usability, engagement, and conceptual understanding may not fully reflect broader or more diverse learner populations Second, the study relied on self-reported data from surveys and interviews, which are subjective and may be influenced by social desirability or immediate impressions. Qualitative insights, drawn from a small subset of participants, provide depth but may not capture the full range of user experiences. Third, the study assessed only short-term interactions with the BID app, limiting insights into how engagement, usability, and learning outcomes might evolve with sustained use. Moderate ratings for conceptual understanding may reflect limited exposure rather than app limitations. Future research should employ larger, more diverse samples, longitudinal designs, and performance-based measures to more rigorously evaluate the impact of AI-powered BID tools.

Conclusion and Implications

This project demonstrates how AI technologies can be effectively incorporated into educational tools to teach complex, interdisciplinary concepts like bio-inspired design. The design process involved technical exploration, user-focused interface development, and iterative improvements to create an application that is both functional and educationally effective. The resulting app offers a platform for students to explore the connection between biology and design through interactive, image-based learning. Together, these technological advances greatly improve students' ability to understand and apply the structure-function-mechanism framework, thus supporting a deeper integration of biology-inspired design in education. Image recognition, digital notebooks, AI chatbots, and augmented reality each play a unique role in making SFM concepts more accessible, engaging, and tailored to individual learners. As research and development in educational technology progress, these tools show strong potential for preparing students to approach BID with the analytical precision and creativity required by modern engineering challenges.

The findings of this study have important implications for engineering education at the precollege level. These findings suggest that interactive, user-friendly digital tools like the BID app can play a valuable role in pre-college engineering education by increasing engagement and lowering barriers to entry for novice learners. However, to support deeper conceptual understanding, such tools should be intentionally integrated into structured instructional approaches, such as inquiry-based or design-centered learning, with appropriate scaffolding. For the pre-college engineering education community, this highlights the importance of pairing engaging technologies with pedagogically grounded implementation to ensure meaningful and lasting learning outcomes.

Future Work

In the next phase of this app development, we plan to enhance EcoView by integrating explicit structure–function–mechanism connections, richer problem-solving tasks, and adaptive scaffolding to support deeper conceptual learning. We will also conduct classroom-based testing to evaluate usability, engagement, and learning outcomes in real instructional settings using pre- and post-assessments, performance tasks, surveys, and teacher feedback. Testing across diverse grade levels and school contexts will ensure accessibility. Finally, longitudinal studies will examine how repeated app use supports cumulative understanding of BID principles, interdisciplinary thinking, and STEM identity development. Iterative cycles of deployment, evaluation, and refinement will guide improvements and inform best practices for AI-supported, biology–engineering education in K–12 classrooms.

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