Exploring High School Student Perceptions of Micropaleontology Learning Through an Interactive FossilSketch Application

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Abstract

FossilSketch is an educational web application designed to teach microfossil identification through interactive activities, including videos, mini-games, and exercises. By connecting fossil identification to real-world environmental change, FossilSketch has the potential to foster awareness of topics ranging from ocean processes to climate change. Although designed for college students, in this study, we argue that FossilSketch is a novel application tool with the potential to introduce micropaleontology concepts to high school students. For this reason, we introduced FossilSketch during a long-running outreach program Sea Camp, a residential summer educational camp in Texas A&M Galveston that engages students in hands-on marine science, ecology, and environmental research experiences.

In this study, we describe an integration of FossilSketch application in three separate cohorts. During the outreach camp, participants engaged with FossilSketch for a ~120-minute session, during which they explored microfossil-focused activities. Each cohort participated in activities that included a brief lecture-style introduction to microfossils by an expert, followed by a FossilSketch session. The FossilSketch session featured interactive mini-games and exercises that allowed students to practice fossil identification and apply their newly acquired skills to environmental reconstructions. With each iteration of the outreach camp, additional activities were introduced to provide students with more direct environmental examples, helping link fossil evidence to modern climate and ecological issues.

To explore students' perceptions about FossilSketch in this outreach setting, students completed an open-ended questionnaire at the end of the learning session. The questions were designed to capture students' perceptions of micropaleontology and their engagement with FossilSketch. A total of 68 student responses were collected over two years. The first cohort (2024) participated before the introduction of regionally specific environmental exercises, and the two subsequent cohorts (2025) used FossilSketch after the new locally focused exercises were introduced. In this paper, we provide a synthesis of students' perceptions across years and answer the following question: 1) How do students' perceptions about micropaleontology knowledge, depth of disciplinary understanding, and their enthusiasm change over time as more targeted environmental activities are introduced in FossilSketch?

The data were analyzed using a multi-method approach. First, we used qualitative content analysis to code open-ended responses, identify common themes, and derive takeaways. Second, we applied descriptive analysis to summarize how students perceived the FossilSketch activities. Third, we compared the results across the two years to assess whether the addition of locally focused environmental activities influenced students' learning and interest. Additionally, data were coded for students' positive, negative, and neutral perceptions to determine whether participation in FossilSketch has changed students' enthusiasm for micropaleontology across cohorts. Results indicate a clear shift across cohorts from morphology-focused descriptions toward applied and integrative environmental reasoning, with students in the 2025 implementations more frequently demonstrating higher-level micropaleontology knowledge, and

application of micropaleontological concepts, while overall student interest in micropaleontology remained stable across cohorts.

This study is novel and contributes insights into how blended approaches (combining digital games, videos, and traditional instruction) can influence high school students' perceptions in specialized scientific disciplines. Furthermore, the results help clarify the utility of FossilSketch by demonstrating how location-based educational activities can engage high school students in gathering and interpreting place-specific data, fostering early familiarity with the scientific tools used to study environmental change.

Introduction

In Science, Technology, Engineering, and Mathematics (STEM) disciplines, literature suggests that early exposure to authentic scientific practices could influence students' academic outcomes, such as persistence and long-term participation in STEM fields, particularly for students who may not otherwise encounter discipline-specific learning opportunities [1], [2], [3].

For these early exposures, informal and outreach-based learning environments can provide an effective context for STEM learning [4], [5]. These environments expose students to scientific ideas while engaging them interactively through authentic experiences [5]. They are most effective when they involve students in low-pressure, exploratory settings that emphasize collaboration, inquiry, and hands-on activities [1], [6], [7], [8]. However, student engagement may be limited in disciplines that rely heavily on abstract reasoning, indirect evidence, extended temporal frameworks, or specialized resources, as conceptual barriers can reduce accessibility and perceived relevance [9], [10]. Examples of such disciplines include Earth system science, climate change, and geology, which can present significant challenges when translated into engaging learning experiences for high school students [11], [12].

Empirical studies in geoscience education consistently indicate that students frequently perceive these fields as predominantly descriptive rather than analytical, which constrains their capacity to link evidence with environmental interpretation and societal relevance [12], [13]. Also, it is often harder to introduce certain topics (e.g., micropaleontology) to students. These topics require resources that are not widely available and are not made accessible to high school students. For example, in micropaleontology, learning to identify and interpret microfossils requires access to microscopes, fossil collections, and teachers with specialized knowledge [14]. It also takes class time to provide personalized feedback, which can be hard to fit into typical course schedules. Consequently, students frequently engage with microfossils solely through static images or simplified descriptions, limiting their experiential learning and constraining deeper comprehension of micropaleontological concepts. This restricted exposure impedes the development of critical analytical skills necessary for interpreting microfossil evidence within broader environmental and geological contexts [11], [12], [15].

Due to these challenges, drawing on principles of active and self-regulated learning, we developed FossilSketch. This novel app introduces various interactive activities that evolved from basic morphology recognition into scaffolded, multi-step genus-level identification tasks, allowing students to practice individual diagnostic features and integrate ecologically relevant morphotype concepts [8, 15, 16]. In 2025, we added increasingly targeted environmental exercises [17], [18], such as Matagorda Bay exercises. This is a region along the Texas Gulf Coast, a recognizable location for participants, in this exercise, students learn to recognize shifts in stress-tolerant and stress-sensitive benthic foraminiferal and ostracod assemblages to reconstruct ecosystem changes over the past 300 years. While this application is designed for undergraduate students [16], [17], [18], we envision the FossilSketch as an effective tool for teaching micropaleontology concepts to high school students. Thus, we introduced FossilSketch into a long-running outreach camp for high school students, Sea Camp, held at Texas A&M Galveston, that provides hands-on exposure to marine science.

This study examines how interactive micropaleontology modules influence high school students' perceptions of paleontological science across years. More specifically, the following research question is answered:

1) How do students' perceptions about micropaleontology knowledge, depth of disciplinary understanding, and their enthusiasm change over time as more targeted environmental activities are introduced?

Design of FossilSketch

Drawing on principles of active and self-regulated learning, FossilSketch was designed as a web-based educational tool to support self-paced engagement with micropaleontological concepts [16], [19]. The application provides instructor and student dashboards [20]. For students, it provides a flexible environment that guides them through structured learning sequences, allowing independent progression and providing automated feedback without direct instructor intervention [21]. Figure 1 provides a glimpse of FossilSketch interface and modules.

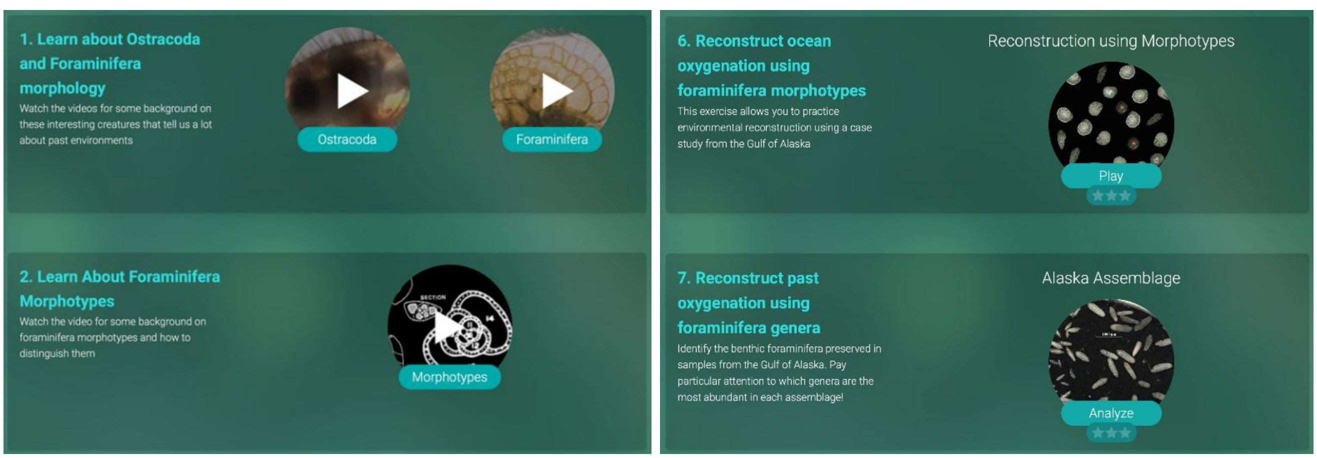

Figure 1. Example of FossilSketch modules and interface

Content is organized into modular units accessed through a student dashboard that allows learners to track progress and performance. Each module follows a consistent structure composed of three activity types[22]: educational videos, interactive mini-games, and applied exercises. Educational videos introduce core micropaleontological concepts and identification principles. Mini-games reinforce key skills such as recognizing diagnostic morphological features. Applied exercises require students to integrate these skills to analyze more complex scenarios, including microfossil assemblages and environmental interpretation.

Across modules, task complexity increases progressively to support the development of applied disciplinary understanding. Automated feedback is provided after each activity, enabling students to evaluate their performance and iteratively refine their understanding.

Literature review

Micropaleontology is a subdiscipline of paleontology focused on the study of microscopic fossil organisms, smaller than 2 mm, preserved within sedimentary deposits, encompassing a substantial portion of Earth's geological timeline [23], [24]. These microfossils include groups such as Foraminifera and Ostracoda, which exhibit distinctive morphological characteristics that enable paleontologists to identify taxa, and use them to reconstruct fossil assemblages, and infer past environments [23], [25], [26]. Microfossils play a crucial role in reconstructing past ecological and environmental conditions. Variations in species composition, shell morphology, and community structure provide valuable insights into changes in factors such as temperature, productivity, oxygen levels, salinity, and carbon cycling [23], [25], [26]. Beyond academic research, micropaleontology has applications in environmental monitoring, basin analysis, and hydrocarbon exploration [25]. Despite its pivotal role in climate change research, environmental monitoring, and Earth system science, micropaleontology is infrequently incorporated into undergraduate and high school curricula. Instruction in these educational settings often prioritizes macroscopic fossil analysis, thereby overlooking the analytical approaches and insights provided by the study of microscopic fossil organisms.

A key challenge to more widely including micropaleontology in high school and undergraduate programs is that traditional teaching methods require substantial resources [27]. Self-regulated learning theory emphasizes the importance of instructional designs that empower students to manage their own learning processes by controlling the pace, monitoring their progress, and engaging in repeated practice with feedback [28], [29]. This approach is linked to enhanced academic performance, increased motivation, and sustained persistence in both traditional classroom settings and online learning environments [28], [29], [30]. Integrating these principles into micropaleontology education, for example, could address resource constraints by enabling students to interact with digital or virtual microfossil resources at their own pace, receive timely feedback, and develop analytical skills more effectively despite limited access to physical specimens or expert instructors [1], [7], [8], [28], [31].

The research on place-based learning demonstrates the importance of contextualizing scientific instruction within environments and issues that students find familiar or meaningful [32], [33], [34], [35]. This approach enhances engagement by linking abstract disciplinary concepts to tangible geographic regions, local environmental phenomena, or regionally relevant datasets, reinforcing both conceptual understanding and engagement with the subject matter.

Modular instructional designs that incorporate distinct locations or environmental contexts align well with this framework, offering varied entry points that accommodate diverse student backgrounds and prior knowledge [32], [35], [36]. This strategy is especially valuable in outreach and informal education, where limited instructional time necessitates maximizing relevance and fostering positive attitudes to encourage sustained interest and further learning. For example, modules could focus on regional assemblages, linking microfossil evidence to familiar landscapes or environmental challenges. This place-based emphasis would not only ground abstract micropaleontological concepts in accessible, real-world settings but also enhance student motivation and comprehension through personal relevance.

Research Methods

We used a multi-method approach[37] to understand students' perspectives on micropaleontology based on their learning from FossilSketch.

Site and Participants

This study was conducted at a residential summer camp at Texas A&M Galveston focused on teaching students about ecology and marine biology through immersive, hands-on experiences. The program engages participants in field-based and laboratory activities designed to build foundational knowledge of marine ecosystems, biodiversity, and environmental processes. FossilSketch was implemented across three outreach camp cohorts spanning two years. These modules varied in their scientific focus and degree of place-based contextualization, allowing us to examine how relevance to recognizable environments or regional contexts shaped student experience. A total of 68 student responses were collected across all three cohorts (Cohort 1: N1 = 25, Cohort 2: N2 = 23, and Cohort 3: N3 = 20). The first cohort (2024) participated before the introduction of regionally specific environmental exercises, and the two subsequent cohorts (2025) used FossilSketch after the new locally focused exercises were introduced.

Cohort 1 completed FossilSketch activities centered on a Pleistocene Alaska case study, which provided a paleontological context but was not geographically local to the students. This cohort was instructed by instructor #1. Cohort 2 engaged with FossilSketch after the introduction of locally focused environmental modules centered on the Matagorda Bay region along the Texas Gulf Coast, a recognizable location for participants. These modules included two foraminifera-based exercises and one ostracod-based exercise that emphasized recent, regionally relevant environments. This cohort was instructed by instructor #2. Cohort 3 had a mixed-module structure combining one Alaska-based foraminifera exercise with one Bay ostracod exercise and was instructed by instructor #1.

Across cohorts, FossilSketch activities were implemented during scheduled instructional blocks within the outreach program. Each group engaged with the FossilSketch modules for approximately the same amount of instructional time (approximately 120 minutes total per cohort), ensuring that differences in student experience were driven by module content and contextual framing rather than exposure duration.

Data Collection

To capture students' perceptions of micropaleontology and their engagement with FossilSketch, students completed an open-ended questionnaire at the conclusion of the FossilSketch use. Before participation, all students and their guardians signed the assent and consent forms (IRB Study 2024-0500) in accordance with university human-subject research guidelines. The questionnaire consisted of three prompts that asked students to reflect on:

1. In what ways has the use of FossilSketch shaped your understanding of micropaleontology?
2. In your understanding, what does micropaleontologists work encompass?

3. Would you like to learn more about the micropaleontology concepts? If yes, why? If not, why not?

Responses were collected and compiled across cohorts to enable across-year comparisons.

Procedure and Data Analyses

We compared the cohorts across three dimensions: 1) micropaleontology knowledge, 2) depth of understanding of micropaleontology disciplinary concepts, and 3) students' enthusiasm for micropaleontology.

First, to assess the scope of micropaleontology knowledge, we conducted a qualitative content analysis on all open-ended responses. For the process, we used summative and direct content analysis approaches. We used open coding and a deductive approach to identify students' perceptions and developed a structured codebook. Codes reflected specific conceptual categories, including references to microfossils, past environments, current environments, environmental influences on organisms, identification skills, lab work, ocean processes, and explicit comparisons between past and present environments. Additional codes captured whether students indicated expanded general knowledge or stated that they now understood what micropaleontology is. Each response was dichotomized (presence/absence) using predefined codes, resulting in a binary matrix. A single researcher conducted coding to maintain internal consistency across cohorts. Because only one coder performed the analysis, inter-rater reliability statistics were not calculated.

Second, to compare the depth of students' micropaleontological concepts, we scored the responses using a structured rubric (Table 1). The rubric captures increasing levels of disciplinary knowledge and application, with each student scored on a scale from 0 to 3+, where 0 indicates the absence of disciplinary understanding, and 3+ indicates excellence in describing micropaleontological concepts and their application. Learning outcomes, categorized into four rubric levels (0, 1, 2, and 3+), represent increasing depth of conceptual understanding.

Table 1. Structured rubric for students' open-ended response evaluation.

0	1	2	3+
No relevant Content	Basic recognition	Morphological or ID detail	Applied understanding or extended application
No content demonstrating understanding of micropaleontology is provided.	Responses reference microfossils or fossils in a general manner.	Responses include information on microfossil ID or morphology (e.g., shape, texture, diagnostic features).	Response connects micropaleontology to a real-world or paleoenvironmental application at least once

After coding using the rubric, we compared cohorts and assessed whether introducing locally focused, place-based environmental activities influenced students' learning about micropaleontology. Attention was given to differences between Cohort 1, which used only non-local modules, and Cohorts 2 and 3, which incorporated regionally relevant exercises. To compare the cohorts, we conducted descriptive statistics and the Kruskal–Wallis test to assess whether median rubric scores differed significantly across cohorts. Given the significant difference, we further conducted post hoc pairwise Mann–Whitney U tests with Holm correction to identify specific cohort contrasts. Effect size was calculated using eta-squared derived from the Kruskal–Wallis H statistic ($\eta^2[H]$) to estimate the magnitude of cohort-level differences in rubric performance.

Third, we compared students' survey responses and examined changes in students' expressed enthusiasm toward micropaleontology across cohorts. Responses were categorized based on stated intent to continue learning and coded as positive (Yes), neutral, or negative (No). The classification was analyzed using descriptive methods, allowing assessment of whether increased contextual relevance and module design corresponded with shifts in students' expressed learning enthusiasm over time.

For statistical analyses, we used R (R Core Team, version 4.4.2). All tests applied a significance threshold of $\alpha = 0.05$. Results are presented alongside descriptive statistics to facilitate interpretation of cohort-level differences. Due to the outreach-based design and varying instructional contexts, findings are interpreted as comparative associations rather than causal relationships.

Results

Micropaleontology Knowledge

The qualitative content analysis identified clear shifts in the disciplinary understanding across the three cohorts. In cohort 1, responses showed low-level descriptions of microfossil morphology, with students primarily referencing observable traits such as shape, texture, and taxonomic identification, and with limited application to environmental interpretation. Within this cohort, only a small proportion of responses explicitly linked microfossils to modern environmental contexts (4%), whereas more references were to past environments (36%). For example, a student mentioned, "*I think its interesting but there is not a lot of practical application*."

However, in Cohort 2, students provided comments that reflected applied environmental reasoning rather than morphology-only descriptions. More responses connected microfossils to past environments (43%), and a substantially larger proportion of students explicitly applied micropaleontological evidence to modern environmental conditions (36%). For example, a student wrote, "*Micropalaeontologists study and sort microfossils to better understand the past, prepare for the future and measure the health of an area, ecosystem, or specific animal species*."

This pattern persisted in Cohort 3, in which connections to modern (20%) and past (30%) environments remained common, indicating a sustained shift toward a broader disciplinary understanding across program iterations. A student mentioned, "*Micropaleontologists work to study the small fossils that help environmental threats at different periods of time as well as improve understanding of our current world.*"

Disciplinary Depth of Micropaleontology Concepts

We used students' scores from the rubric in Table 1 to assess their understanding of micropaleontological concepts. The results indicate that student understanding of micropaleontology concepts differed substantially across cohorts, with both Cohort 2 and Cohort

3 implementations showing clear improvement relative to Cohort 1 (Figure 2). In Cohort 1, student responses were concentrated in lower and intermediate rubric categories, yielding a lower mean score (2.44 ± 1.19; median = 2.0). Most students demonstrated basic recognition or morphological understanding, and applications were largely restricted to past environments, with minimal reference to modern environmental contexts. However, in Cohort 2, a pronounced shift toward higher-level understanding and application was observed. This cohort achieved the highest overall performance, reflected in a substantially higher mean score (4.04 ± 1.87; median = 4.0) and a broader distribution of responses across advanced rubric categories. In Cohort 2, students were markedly more likely to articulate applied reasoning, including connections to both past and modern environmental systems. Also, Cohort 3 demonstrated improved learning outcomes relative to Cohort 1, with no responses in the lowest rubric categories and a higher mean score (2.75 ± 1.02; median = 2.0). While median scores remained similar to Cohort 1, the distribution of responses shifted toward higher-level categories, and students more frequently articulated applied interpretations, including links to modern environments.

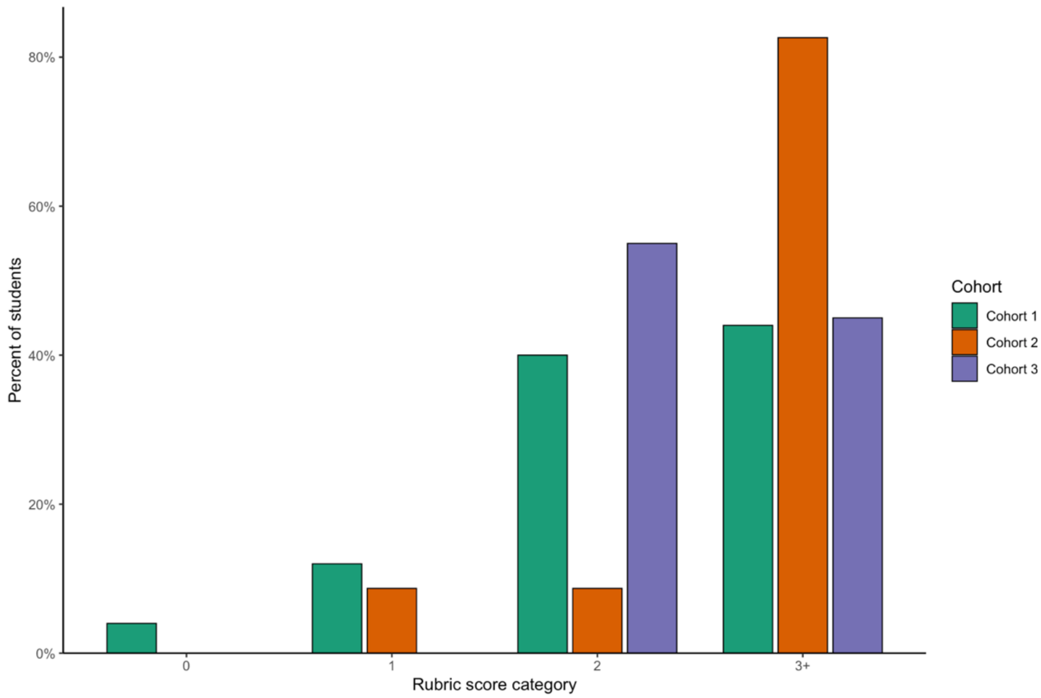

Figure 2. Distribution of student assessment scores across three program cohorts

Further, we conducted a Kruskal–Wallis test to examine the difference between cohorts. The results indicated a statistically significant difference in rubric scores across cohorts, $H(2) = 11.98$, $p = 0.003$. Effect size analysis revealed a moderate-to-large cohort effect ($\eta^2[H] = 0.15$). Post hoc pairwise comparisons using Mann–Whitney tests with Holm correction demonstrated that Cohort 2 students had significantly higher understanding than both Cohort 1 ($p = 0.004$) and Cohort 3 ($p = 0.021$). In contrast, Cohort 1 and Cohort 3 did not differ significantly ($p = 0.427$).

In Cohort 1, responses were distributed across all outcome categories, with many students demonstrating an intermediate understanding of micropaleontology (score 2; n = 10) and a smaller proportion demonstrating an applied understanding (score 3+; n = 11). In contrast, in Cohort 2, students showed a strong shift toward applied outcomes, with most responses falling within the 3+ category (n = 20) and very few responses in lower categories. Cohort 3 similarly showed no responses in the lowest categories (scores 0 or 1), with outcomes concentrated in scores 2 (n = 11) and 3+ (n = 9). Together, these distributions indicate that students in both Cohort 2 and 3 were more likely to demonstrate applied understanding than those in Cohort 1.

We also noticed clear differences in how students conceptualized micropaleontology across cohorts, with later cohorts articulating more integrative and applied understandings of the field. For example, Cohort 1 student responses primarily emphasized basic identification and reconstruction of past environments, often focusing on descriptive aspects of the discipline. For example, one student stated, *"identifying species and using them to learn about past environments,"* while another described micropaleontology as encompassing *"ocean dead zones, what the past oceans looked like, old organisms, how the oceans have changed and more."* However, Cohort 2 students demonstrated more expansive and applied conceptions of micropaleontological work, frequently linking past, present, and methodological practices. One student explained, *"Micropaleontologists' work encompasses understanding, searching and finding the ways the ocean used to work. It tells us understand why things happened in the past and compare to now to better help new situations and it helps us understand and final bits of the past we may have never known before searching."* Similarly, Cohort 3 students emphasized forward-looking and integrative applications of micropaleontology. One student described the field as *"Understanding the connection between microfossils and past life on Earth as well as how their information can better imagine our future environment"*.

Students' Perceptions of Micropaleontology

Across all cohorts, student enthusiasm towards learning more about micropaleontology remained broadly consistent, regardless of module design or instructional emphasis (Figure 3). While the relative proportions of "Yes" and "No" responses varied modestly across cohorts, none showed a substantial shift in interest. These results suggest that baseline student enthusiasm for micropaleontology is relatively stable across outreach implementations and is not strongly dependent on the specific exercise type.

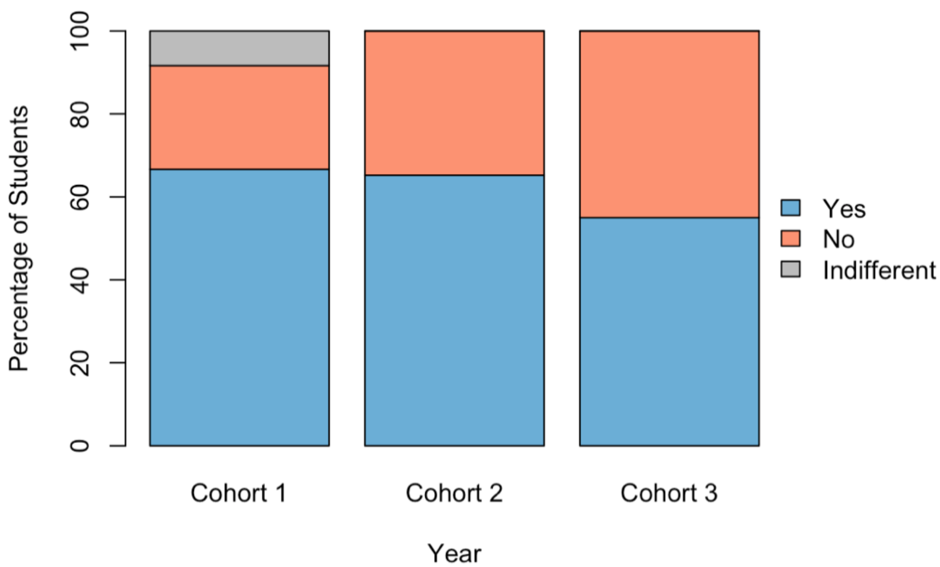

Figure 3. Distribution of student responses to whether they would like to learn more about micropaleontology across cohorts.

Discussion

This study examined how high school students' perceptions of micropaleontological knowledge, depth of disciplinary understanding, and enthusiasm for the field evolved after engaging with FossilSketch across three outreach cohorts. Interpreted through a self-regulated learning (SRL) framework, the findings suggest that the application's structure, combined with contextualized environmental modules, supported students' progression from surface-level recognition to more strategic and applied disciplinary reasoning.

The results indicated a clear progression in students' disciplinary understanding across cohorts, particularly following the introduction of locally contextualized environmental modules. Cohort 1 responses were largely descriptive, emphasizing morphology and identification, whereas Cohorts 2 and 3 more frequently articulated connections between microfossil evidence, past environmental reconstruction, and modern ecological conditions. This shift suggests that embedding micropaleontological tasks within recognizable environmental contexts helped students move beyond taxonomic recognition toward integrative reasoning. One potential explanation is familiarity with geographic settings, which may have reduced abstraction for students. These results align with existing research suggesting that contextual relevance enhances conceptual integration and disciplinary thinking [14].

Rubric-based comparisons further demonstrated that students in Cohort 2, and to a lesser extent Cohort 3, achieved higher levels of applied conceptual understanding than those in Cohort 1. The statistically significant differences in rubric performance, particularly the strong shift toward the highest category (3+) in Cohort 2, indicate that students were not only recognizing morphological features but also applying microfossil evidence to interpret environmental change. This improvement could be due to the targeted environmental exercises. Also, the stronger performance of Cohort 2 compared to Cohort 3 suggests that a fully place-based module (rather than a mixed structure) may provide more coherent cognitive framing, reinforcing literature indicating that contextual consistency strengthens learning transfer in geoscience settings [32]. These results extend prior findings by demonstrating that digital, scaffolded tools can effectively promote applied reasoning in resource-intensive disciplines like micropaleontology, which traditionally require laboratory infrastructure and expert guidance [10].

In contrast to cognitive outcomes, student enthusiasm toward learning more about micropaleontology remained relatively stable across cohorts, regardless of module design. This result provides additional information from measuring students' perceptions or sentiments, as most previous studies only captured a one-time perception of students post-use of the application [38]. While place-based contextualization improved applied reasoning, it did not produce a measurable shift in expressed enthusiasm. This divergence highlights an important distinction between cognitive gains and affective change in short-term outreach contexts. Research in informal science learning suggests that while authentic and inquiry-based experiences can positively influence engagement, shifts in long-term interest and academic identity often require sustained exposure rather than single-session interventions [1], [2]. It is therefore plausible that the 120-minute module was sufficient to enhance disciplinary reasoning but insufficient to alter affect significantly

Limitations

Several limitations should be considered when interpreting these findings. While both instructors followed the same materials and objectives, variations in instructional style, emphasis, and classroom interaction may have influenced student engagement and response patterns. The timing of module delivery within each camp week differed, which may have influenced student engagement, overall fatigue, or cognitive load. Additionally, each camp cohort participated in slightly different overarching program topics, potentially shaping baseline interest in micropaleontology independent of module design. While participants fell within the same general age range, minor differences in grade level and prior exposure to Earth science may also have contributed to variability in conceptual performance. Finally, the place-based module design was implemented with a limited number of cohorts; replication across additional groups would strengthen confidence in the observed instructional effects and allow for more robust evaluation of contextual relevance as a driver of applied understanding.

Conclusion

This study examined how high school students' perceptions and understanding of micropaleontology evolved after engaging with FossilSketch across three outreach cohorts. The findings show a clear shift from morphology-focused descriptions toward more applied reasoning about environmental change, particularly after the introduction of locally contextualized modules. These results suggest that integrating interactive educational tools with place-based environmental examples can help students move beyond basic recognition toward deeper disciplinary understanding, even within a short outreach experience.

The study also has broader implications for STEM and engineering education. Many scientific and engineering disciplines require students to interpret indirect evidence, analyze data patterns, and reason about complex environmental systems. The learning processes observed in this study, such as interpreting microfossil evidence and linking it to environmental change, parallel analytical practices used in fields such as environmental and civil engineering. Educational scaffolded applications like FossilSketch therefore offer a promising approach to introducing students to evidence-based reasoning and systems thinking, which are central to engineering education.

At the same time, the findings indicate that improvements in disciplinary understanding did not correspond to substantial changes in students' expressed enthusiasm for learning more about micropaleontology. This suggests that while short-term digital learning modules can support conceptual development, shifts in long-term interest may require repeated exposure and continued engagement with the discipline.

Future research should investigate how sustained or repeated use of place-based digital learning tools influences students' STEM trajectories, including interest in geoscience and engineering-related fields. Expanding the implementation of FossilSketch across diverse educational settings and integrating similar modules into formal STEM or introductory engineering learning environments could further clarify how digital, context-rich instruction supports interdisciplinary STEM learning and broadens participation in these fields.

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