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Digital plant project in biology education: Bridging sociodemographic gaps in plant awareness

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ABSTRACT

Plant awareness disparity poses a persistent challenge in biology education, limiting recognition, appreciation, and engagement with plants among preservice biology teachers (PSTs). This study investigated the influence of sociodemographic factors on PSTs' plant awareness gains and evaluated the effectiveness of a digital plant project in addressing these disparities. A total of 134 PSTs participated in a project-based intervention involving observation, documentation, and analysis of local plants using digital tools. Plant awareness was measured through the validated Plant Awareness Disparity (PAD) Questionnaire, which covers four indicators: attention, attitude, knowledge, and relative interest. Sociodemographic data, including gender, age, residence, family income, family experience with plants, and plant-based cultural practices, were analyzed using t-tests and one-way ANOVA. The results showed significant improvements across all indicators of plant awareness after the intervention. Gender, residence, family income, family experience, and cultural practices significantly affected awareness gains, while age did not. Female students, urban residents, and participants from higher-income or plant-engaged families achieved higher gains. The digital plant project fostered active, experiential, and technology-supported learning, enabling equitable participation and engagement with botanical content. Overall, the findings highlight the potential of integrating digital and project-based approaches in biology education to enhance both conceptual understanding and affective appreciation of plants, while supporting inclusive curricula that address disparities in plant awareness.

INTRODUCTION

Plant awareness is a fundamental aspect of biological literacy (Stagg et al., 2024; Uno, 2009), encompassing the capacity to acknowledge, value, and comprehend the significance of plants in human life and ecological systems. Recent studies have reinforced this view, emphasizing that plant awareness is central to fostering environmental stewardship and sustainable thinking in biology education (Amprazis & Papadopoulou, 2020; Parsley, 2022). Yet, this awareness is frequently overshadowed by what researchers' term "plant awareness disparity" (PAD), a cognitive bias in which individuals unconsciously undervalue or overlook plants in favor of animals or more visually engaging aspects of biology (Parsley, 2020). This disparity has profound implications for biology education, as it can shape how future educators conceptualize the living world and what they emphasize in their own teaching. The persistence of this disparity reflects not only limited botanical exposure but also deeper sociocultural and demographic factors influencing how individuals perceive plant life.

As future biology educators, PSTs play a pivotal role in either perpetuating or challenging this bias. Their perceptions, attitudes, and experiences with plants will inevitably influence their instructional choices and, in turn, the biological literacy of their future students (Bobo-Pinilla et al., 2023; Eugenio-Gozalbo et al., 2024). Several studies have reported that even preservice teachers, although enrolled in biology-focused programs, often exhibit limited plant awareness and face difficulties in engaging with botanical content (Balding, 2016; Stroud et al., 2022). This trend may be attributed not only to curriculum gaps but also to the lack of immersive and authentic learning experiences related to plants during teacher preparation (Telli, 2025). In Indonesia and many other contexts, plant-related instruction is often reduced to theoretical content with limited hands-on exploration, field-based inquiry, or use of technology (Hartanti et al., 2024; Karno et al., 2024). Consequently, PSTs may graduate with inadequate understanding or appreciation of plant diversity, structure, and ecological importance, which in turn perpetuates plant blindness in the next generation of learners.

Addressing this issue requires not only pedagogical innovation but also awareness of the sociodemographic contexts that shape learning. Factors such as gender, geographic origin (urban or rural), and socioeconomic background may influence how PSTs experience and value the plant world. (Marcos-Wallas et al., 2023; Stagg, 2022). In regions with limited environmental access, whether caused by urbanization or economic constraints, students may encounter fewer opportunities to engage directly with flora, resulting in varied baseline awareness. Thus, the problem of plant awareness disparity must be understood within a broader framework of social and demographic diversity (Sanders et al., 2020). Bridging these sociodemographic gaps is essential to create equitable opportunities for developing plant literacy among future biology educators. However, there is still limited empirical evidence exploring how these sociodemographic factors intersect with learning interventions that promote plant awareness within teacher education contexts. This gap highlights the urgency of designing innovative, inclusive learning strategies that not only enhance plant awareness but also reduce social inequalities in educational outcomes.

One promising avenue to address PAD and promote inclusiveness in teacher education is the use of a digital plant project that integrates technology-based documentation and creative visualization of plant diversity. The rapid development of digital tools and visual media has provided opportunities to make botanical content more engaging, accessible, and contextually relevant (Shao, 2024). By integrating multimedia documentation, infographics, and digital platforms into plant-based tasks, students can engage with plants not just theoretically but visually and interactively (Burke et al., 2022). These projects, when embedded in teacher training programs, may serve as meaningful interventions to foster plant awareness and connect PSTs with the living world around them in more tangible ways. Previous research has shown that digital learning environments can enhance environmental and botanical literacy through active, student-centered learning (Arslan & Karakuş, 2024; Chien et al., 2019). However, studies specifically examining digital interventions to address PAD among preservice teachers are still scarce, representing a key gap this study aims to address.

In this study, a digital plant project was implemented as an intervention designed to both enhance plant awareness and bridge sociodemographic gaps among preservice biology teachers. The project involved identifying a plant species, analyzing its morphological structures, visually documenting those structures, and producing an infographic for inclusion in a digital plant encyclopedia. The activity served not only as an alternative learning strategy to promote plant literacy but also as a mechanism for PSTs to reflect on the role of plants in ecosystems, daily life, and education. Importantly, the integration of digital technologies was intentional to support student learning, creativity, and digital competency while simultaneously promoting equity in engagement and access. Such approaches have been shown to deepen understanding by encouraging students to actively observe, document, and articulate what they learn (Pinto & Leite, 2020; Zou et al., 2025). This study therefore positions the digital plant project as a response to the identified research gap, aligning plant awareness development with inclusive and technology-enhanced pedagogy in biology education.

Despite the growing interest in improving plant literacy, little empirical research has examined the intersection between plant awareness, digital learning interventions, and sociodemographic diversity, particularly within teacher education. This study therefore seeks to fill that gap by investigating how a digital plant project can address plant awareness disparity while bridging differences arising from sociodemographic factors. Specifically, the study aims to: (1) assess whether participation in the digital plant project improves PSTs' plant awareness overall, and (2) evaluate the influence of sociodemographic factors on awareness gains.

METHODS

Research Design

This study follows a quasi-experimental pretest–post-test design with a single-group intervention. which allows the comparison of participants' performance before and after the treatment without the use of a control group (Creswell & Creswell, 2017). The objective is to investigate the impact of a digital plant project integrated into biology teacher education on addressing plant awareness disparity and bridging sociodemographic gaps among preservice biology teachers. The design allows for the evaluation of the intervention's effectiveness by comparing participants' plant awareness levels before and after the implementation of the project. Additionally, the study examines whether changes in plant awareness differ according to sociodemographic characteristics such as gender, geographical background, and previous exposure to nature. This approach provides insight into both the overall effectiveness of the digital project and its potential to promote more equitable learning outcomes across diverse student populations.

Population and Samples

The population of this study consisted of 535 PSTs enrolled in the Biology Education Department at a public university in West Java. This population was chosen because it represents future educators who will play a crucial role in shaping students' understanding of biological and ecological concepts, including plant diversity and the importance of plants in ecosystems. From this population, a sample of 134 PSTs was selected using a purposive sampling technique. The sample was drawn from students enrolled in the Phanerogams (flowering plants) course during the 2024/2025 semester, as this course provides a relevant academic setting for implementing the digital plant project. This course emphasizes plant taxonomy, morphology, and classification, aligning directly with the study's aim to enhance plant awareness through digital engagement. All participants were in their second year of study, a phase where they possess foundational botanical knowledge yet continue developing professional teaching competencies. This makes them an appropriate group for investigating both cognitive and attitudinal aspects of plant awareness, particularly in response to digital interventions designed to reduce disparities across sociodemographic lines. The participants varied in sociodemographic backgrounds such as gender, place of residence, and family income, which were analyzed later to examine their influence on plant awareness outcomes.

Instrument

The main instrument used in this study was the Plant Awareness Disparity (PAD) Questionnaire, which was adapted from the framework developed by Parsley (2022) to measure four indicators of plant awareness: attention, attitude, knowledge, and relative interest. The attention indicator measured the extent to which participants notice and focus on plants in their surroundings. Attitude captured their appreciation, emotional connection, and perceived importance of plants in everyday life and education. Knowledge assessed their understanding of plant diversity, structure, and ecological functions, while relative interest evaluated their level of curiosity and engagement toward plants compared to other organisms. Each item was rated on a four-point Likert scale ranging from strongly disagree (1) to strongly agree (4), with higher scores indicating a stronger level of plant awareness. In addition, a sociodemographic questionnaire was administered to collect information such as gender, age, place of residence, family income, family experience with plants, and family plant-based cultural practices to identify awareness disparities among groups.

The PAD questionnaire underwent content and construct validation to ensure its accuracy and reliability. Content validity was reviewed by one expert in biology education at Universitas Siliwangi using a four-point relevance scale, yielding a Content Validity Index (CVI) of 0.90. Construct validity was examined empirically through a pilot study involving 30 PSTs who were not part of the main study sample, using item validity testing in IBM SPSS version 26. The analysis employed the corrected item-total correlation approach, and all items showed correlation coefficients above the minimum threshold of 0.361, indicating that each item was valid and contributed significantly to the overall construct of plant awareness disparity. Overall, Cronbach's alpha coefficient was 0.89, indicating high internal consistency. Therefore, the PAD questionnaire was deemed valid and reliable for measuring plant awareness disparity among preservice biology teachers.

Procedure

The study procedure consisted of three main stages: pre-intervention, intervention using project-based learning, and post-intervention. Before the learning intervention began, participants were asked to complete two initial instruments: the sociodemographic questionnaire and the PAD pretest. These surveys were administered online to collect background data and to measure participants' initial levels of plant awareness across four indicators. Following the pretest, participants engaged in a project-based learning intervention centered on the development of a digital plant encyclopedia called *Botanipedia*. *Botanipedia* is a collaborative digital platform designed to document and showcase plant species through images, morphological descriptions, and ethnobotanical information, serving as both a learning product and an educational resource. The intervention phase was conducted over eight meetings as part of the Phanerogams course, using *Botanipedia* as the central project. Each session was designed to enhance preservice biology teachers' plant awareness through observation, documentation, and digital engagement. The summary of project activities is presented in Table 1. At the end of the eighth meeting, participants completed the PAD post-test to evaluate changes in their awareness and to determine whether the digital project contributed to reducing plant awareness disparity across sociodemographic groups. The pretest and post-test results were later analyzed to assess the effectiveness of the intervention

To ensure consistency across sessions, all groups followed the same instructional plan, materials, and assessment rubrics. The same instructor facilitated all meetings to minimize variability in guidance. Plant materials were prepared and standardized for each session to ensure comparable exposure to plant species. Any deviations in schedule or resource availability were documented to control external factors that could influence learning outcomes. Prior to the intervention, the study objectives, procedures, and voluntary nature of participation were clearly explained to all students. Informed consent was obtained verbally and in writing, ensuring that participants understood their right to withdraw at any stage without penalty. The study was conducted in accordance with institutional ethical standards for educational research.

Table 1.
Summary of the Digital Plant Project Implementation

Meeting	Focus	Key Activities and Outcomes
1	Project orientation	Introduction to objectives, plant awareness disparity concept, and ethical digital documentation.
2	Morphological training	Learning basic plant identification and classification (habitus, leaf, flower, fruit).
3	Field exploration I	Collecting and photographing local plant species, recording field notes.
4	Field exploration II	Verifying plant taxonomy and morphological accuracy.
5	Data compilation	Organizing plant data (scientific/local names, ecological roles, uses).
6	Digital development	Creating digital entries for *Botanipedia* with images and descriptions.
7	Presentation & review	Presenting digital outputs and conducting peer feedback.
8	Reflection	Discussing changes in awareness, attitudes, and interest toward plants.

Data Analysis Techniques

Data were analyzed quantitatively using descriptive and inferential statistics to address the research objectives. Descriptive statistics summarized participants' sociodemographic characteristics and their scores on each PAD indicator (attention, attitude, knowledge, and relative interest). To examine the effectiveness of the digital plant project, paired-sample t-tests were used to compare pretest and posttest scores, and Cohen's d was calculated to determine the effect size. The influence of sociodemographic factors (gender, residence, socioeconomic background, family experience with plants, and plant-related cultural practices) on awareness gains was examined using independent-sample t-tests and one-way ANOVA. Cohen's d was also computed for independent-sample t-tests to indicate the magnitude of mean differences between groups, while partial η^2 values were reported for one-way ANOVA to estimate the proportion of variance explained by sociodemographic factors. All analyses were conducted with a significant level of $p < 0.05$.

RESULTS AND DISCUSSION

The sociodemographic characteristics of the 134 PSTs who participated in this study are summarized in Table 2, which presents the distribution of gender, age, residence, family income, family experience with plants, and engagement in plant-based cultural practices. The sample was predominantly female, with most participants residing in urban areas. The majority came from families with incomes around the minimum wage, and more than half reported having considerable family experience with plants, although fewer indicated engagement in plant-based cultural practices.

Table 2
Sociodemographic Characteristics of Participants (n = 134)

Factors	**n**	**%**
Gender		
Male	13	9.70
Female	121	90.30
Age		
18	9	6.72
19	84	62.69
20	37	27.61
21	4	2.98
Place of residence		
Urban	46	34.33
Rural	88	65.67
Family income		
Below minimum wage (< Rp. 2.500.000)	26	19.40
At minimum wage (Rp. 2.500.000 – Rp. 5.000.000)	66	49.25
Above minimum wage (Rp. 5.000.000 – Rp. 7.500.000)	32	23.88
Well above minimum wage (> Rp. 7.500.000)	10	7.46
Family experience with plant		
None	10	7.46
A little	45	33.58
Quite a lot	74	55.22
A great deal	5	3.73
Family plant-based cultural practices		
Yes	35	26.12
No	99	73.88

The sociodemographic profile of the PSTs shows considerable diversity among participants in this study. Most participants were female and within the 18–21 age range, representing a typical demographic composition in teacher education programs (Ferrer, 2023; Heinz et al., 2021). Participants also came from both urban and rural settings, with varying socioeconomic backgrounds ranging from below to above the minimum wage. Such variation indicates that the participants represent a heterogeneous group in terms of living environment and economic conditions, which enriches the dataset and reflects the broader context of biology education students in Indonesia.

Additionally, participants differed in their family exposure to plants and involvement in plant-based cultural practices. While many reported moderates to high family experience with plants, fewer engaged in traditional or cultural activities related to plant use. This finding aligns with previous studies showing that exposure to plant-related practices often varies across families depending on lifestyle and cultural background (Poncet et al., 2021). This variation provides a foundation for understanding how diverse backgrounds may influence learning outcomes in plant education, highlighting the importance of contextualized interventions in teacher preparation programs.

Building upon this diverse background, descriptive statistics were calculated to examine preservice biology teachers' levels of plant awareness across four indicators: attention, attitude, knowledge, and relative interest, before and after participating in the digital plant project. As shown in Table 3, all indicators of plant awareness improved after the project-based intervention. The attention indicator showed the largest increase (from M = 3.52 to M = 4.04), indicating that students became more observant and mindful of plants in their surroundings. This aligns with theories of experiential learning (Kolb, 1984), where direct engagement enhances sensory perception and reflectionThe attitude indicator also improved (from M = 3.79 to M = 4.06), suggesting a more positive affective response toward plants and their ecological importance. Similarly, participants' knowledge of plant diversity and functions increased slightly (from M = 4.49 to M = 4.67), reflecting a stronger understanding of botanical concepts. The relative interest sub-indicator "plants better than animals" showed a substantial gain (from M = 3.20 to M = 3.56), whereas "animals better than plants" remained nearly unchanged (M = 3.05 to M = 3.04). This pattern indicates that the intervention effectively elevated participants' awareness and appreciation of plants, particularly in balancing the typical bias favoring animals over plant.

Table 3.
Descriptive Statistics of Preservice Biology Teachers' Plant Awareness Before and After the Digital Plant Project

Indicators	Pretest		Posttest	
	Mean	**SD**	**Mean**	**SD**
Attention	3.52	0.13	4.04	0.20
Attitude	3.79	0.22	4.06	0.16
Knowledge	4.49	0.25	4.67	0.14
Relative interest (plants better than animals)	3.20	0.26	3.56	0.22
Relative interest (animals better than plants	3.05	0.09	3.04	0.05

The findings revealed that all four indicators of plant awareness showed improvement after participation in the digital plant project. This overall increase indicates that the intervention successfully enhanced PSTs' awareness and understanding of plants. The most notable gain was observed in the attention dimension, suggesting that students became more perceptive and attentive toward plant life in their surroundings. This aligns with theories of experiential learning (Kolb, 2014), where direct engagement enhances sensory perception and reflection. This outcome also aligns with previous research showing that experiential and inquiry-based learning activities increase students' visual attention and recognition of plants in daily environments (Balas, 2014; Fančovičová & Prokop, 2011). By engaging students in authentic observation and documentation tasks, the project helped counteract the tendency to overlook plants, a phenomenon often described as plant blindness (Margulies, 2019).

The positive change in the attitude dimension suggests a stronger affective connection and appreciation of plants' ecological roles. Similar results were reported by Balding and Williams (2016), who found that direct interaction with plant biodiversity promotes more favorable environmental attitudes among students. This outcome reflects the affective component of plant literacy development, emphasizing that cognitive gains are most effective when accompanied by emotional engagement. In this study, involving students in documenting and describing local flora through digital media not only fostered cognitive engagement but also emotional and ethical appreciation toward plant life, reflecting the holistic goals of plant awareness development (Parsley, 2020).

A modest increase was also observed in knowledge, indicating that students deepened their conceptual understanding of plant diversity, morphology, and ecological functions. Previous studies have emphasized that contextual and project-based approaches enhance conceptual retention and application in botany education (Genc, 2015; Yli-Panula et al., 2018). The integration of digital documentation through *Botanipedia* likely supported this knowledge gain by allowing students to actively construct, visualize, and share information rather than passively receive it (Coşkunserçe, 2024; Hajj-Hassan et al., 2024).

Moreover, the gain in the relative interest sub-indicator "plants better than animals" combined with the stable response for "animals better than plants," indicates a shift toward a more balanced perception of biodiversity. This suggests that the intervention contributed to reducing plant awareness disparity by mitigating the common animal-centric bias described in plant blindness theory. This is a meaningful outcome because it reflects reduced animal centrism, a core component of plant awareness disparity (Forti & Szabo, 2024). Engaging students in projects centered on local plants appears to bridge the perceptual and affective gap between flora and fauna, promoting a more equitable view of living organisms.

Overall, the findings demonstrate that the digital plant project, as a project-based intervention, effectively addressed multiple indicators of plant awareness by combining observation, field experience, and digital engagement. This supports the view that immersive and participatory learning experiences are essential for overcoming plant awareness disparity among future biology teachers (Amprazis & Papadopoulou, 2020). Such outcomes highlight the pedagogical potential of integrating local biodiversity and technology to foster both cognitive and affective indicators of botanical literacy. Before conducting further statistical analyses, assumption testing was performed to ensure that the data met the requirements for parametric analysis. Specifically, normality and homogeneity tests were conducted on the pretest and post-test scores of PSTs' plant awareness, as seen in Table 4.

Table 4.
The Results of Tests of Normality and Homogeneity of Variances

Test	Group	Statistic	df	Sig. (p)	Interpretation
Shapiro–Wilk	Pretest	0.072	134	0.083	Normal
	Posttest	0.070	134	0.200	Normal
Levene's Test for Equality	Pretest vs. Posttest	2.191	(1. 266)	0.140	Homogeneous

The results of the Shapiro–Wilk test indicated that both pretest ($p = 0.083$) and post-test ($p = 0.200$) data were normally distributed, as p-values were greater than 0.05. Additionally, Levene's test showed no significant difference in variance between the two groups ($F = 2.191$, $p = 0.140$), suggesting homogeneity of variances. These findings confirm that the data met the assumptions required for subsequent parametric testing. Since the data met the assumptions of normality and homogeneity, a paired sample t-test was conducted to determine whether there was a significant difference between the pretest and post-test scores (Table 5). This test was used to examine the effect of the treatment on PSTs' awareness by comparing their mean scores before and after the intervention.

Table 5.
The Result of Paired Sample T-Test

Pair	Mean Difference	Std. Deviation	t	df	Sig. (2-tailed)	Cohen's d
Pretest-posttest	0.289	0.506	-6.615	133	0.000	0.868

Table 5 presents the results of the paired-sample t-test comparing pre-test and post-test scores. The analysis revealed a significant difference between the two measurements ($t(133) = -6.615$, $p < 0.05$). The paired sample t-test results showed a significant difference between pretest and post-test scores, indicating a strong positive effect of the digital plant project on PSTs plant awareness. The substantial mean difference ($M = 7.231$, $p < 0.05$) demonstrates that project-based learning can effectively enhance both conceptual understanding and engagement. This aligns with previous findings suggesting that project-based learning encourages active participation, deepens learning, and connects students with authentic ecological contexts (Chang et al., 2024; Thomas, 2000). Moreover, the effect size calculated using Cohen's d (0.868) indicates a large practical impact of the intervention according to Cohen's (1988) classification. The 95% confidence interval for the mean difference further indicates that the improvement in plant awareness was both statistically reliable and practically meaningful, reflecting a consistent effect across participants. Through this digital project, PSTs were not only involved in content exploration but also in reflective observation of local plant diversity and key processes for developing environmental sensitivity and scientific reasoning. An example of students' digital plant documentation output is presented in Figure 1, illustrating the detailed morphological analysis of *Helianthus annuus* (sunflower) produced as part of the digital plant project.

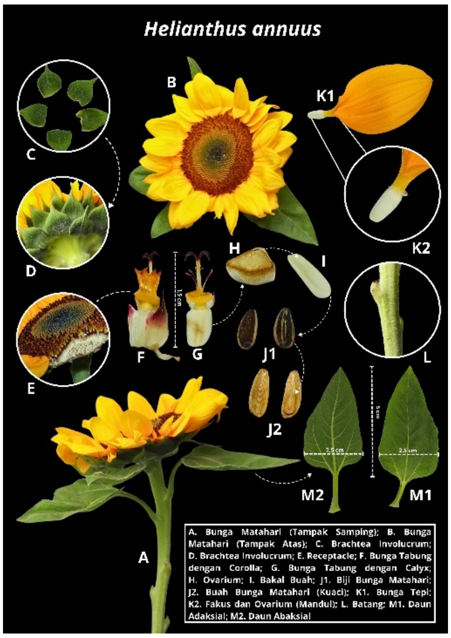

Figure 1. Example of students' digital documentation results in the digital plant project showing morphological structures *of Helianthus annuus (*sunflower*)*.

The improvement observed in the post-test results underscores how digital, project-based activities can foster deeper engagement and critical reflection on environmental content. By encouraging students to explore and document local flora through technology-enhanced inquiry, the intervention transformed abstract biological knowledge into personally meaningful experiences. This experiential engagement promoted curiosity, contextual understanding, and a sense of relevance that are key drivers for sustaining environmental interest among PSTs (Mahapatra & Vijayalatha, 2024). Through this process, participants not only strengthened their conceptual grasp of plant diversity but also developed a more integrated ecological perspective that connects science learning with real-world biodiversity contexts (Fiel'ardh et al., 2023; Le et al., 2018).

Moreover, these findings underscore the pedagogical potential of integrating digital and project-based approaches into teacher education programs. As Balding and Williams (2016) emphasized, enhancing teachers' plant awareness is crucial to cultivating students' appreciation for biodiversity and sustainability. The digital plant project demonstrated how contextualized learning supported by technology can cultivate critical awareness and ecological literacy (Wang et al., 2020). In this sense, the project does not merely serve as a learning experience but as a model for how preservice teachers can design future lessons that bridge scientific knowledge with cultural values and environmental responsibility.

To further explore the factors that might influence students' awareness gains, sociodemographic variables were analyzed in relation to their gain scores (posttest–pretest). Independent-samples t-tests were employed to compare mean gain scores based on gender, residence, and family plant-based cultural practices, while one-way ANOVA tests were used for age, family income, and family experience with plants. These analyses aimed to determine whether differences in awareness gains could be attributed to students' demographic backgrounds, and effect sizes (Cohen's d for t-tests and partial η^2 for ANOVA) were calculated to indicate the magnitude of group differences. For all significant comparisons, 95% confidence intervals were computed to indicate the precision of the estimated mean differences, providing a more robust interpretation of group-level disparities in awareness gains. The detailed results of these analyses are presented in Table 6.

Table 6 presents the results of the analyses examining the relationship between sociodemographic factors and students' awareness gains in the context of the digital plant project. The analyses revealed that gender, residence, family plant-based cultural practices, family income, and family experience with plants significantly influenced awareness gains, whereas age did not show a statistically significant effect. In terms of effect sizes, the Cohen's d values ranging from 0.65 to 0.72 indicate moderate to large effects, suggesting that the observed differences in mean gains between groups were not only statistically significant but also practically meaningful. Similarly, the partial η^2 values for significant ANOVA results (ranging from 0.09 to 0.11) reflect moderate effects according to conventional benchmarks (Cohen, 1988), implying that sociodemographic factors such as income and family experience with plants explain a substantial proportion of variance in awareness gains.

Table 6.
Results of Independent-Samples t-test and One-Way ANOVA on Awareness Gains by Sociodemographic Factors

Factors	Mean Gain	SD	t / F	df	Sig. (p)	Effect Size	Interpretation
Gender	Female = 3.23; Male = 1.79	0.67	2.68	132	0.008	d = 0.65	Significant
Residence	Urban = 3.31; Rural = 1.55	0.62	3.12	132	0.002	d = 0.72	Significant
Family plant-based cultural practices	Yes = 3.09; No = 1.67	0.63	2.94	132	0.004	d = 0.69	Significant
Age	18 = 2.10; 19 = 2.47; 20 = 2.56; 21 = 2.76	0.62	F = 1.02	(3,130)	0.384	η^2 = 0.02	Not significant
Family income	< Rp. 2.500.000= 1.73; Rp. 2.500.000 - Rp. 5.000.000= 2.30; Rp. 5.000.000 - Rp. 7.500.000 = 3.16; (> Rp. 7.500.000= 3.77	0.63	F = 4.26	(3,130)	0.007	η^2 = 0.09	Significant
Family experience with plants	None = 1.00; A little = 1.94; Quite a lot = 3.18; Great deal = 4.00	0.63	F = 5.18	(3,130)	0.002	η^2 = 0.11	Significant

These results reinforce that gender, residence, and family background are influential determinants of students' plant awareness development. Female students, urban residents, and those from families with plant-based cultural practices or greater plant experience demonstrated higher mean gains, suggesting that both personal characteristics and familial/environmental exposure play important roles in shaping PSTs awareness of plants. Additionally, higher family income was associated with larger gains, indicating that economic resources may facilitate access to learning opportunities that enhance plant awareness.

The findings of this study underscore the significant role of sociodemographic factors in shaping PSTs' awareness of plant-related topics. Gender emerged as a pivotal determinant, with female students exhibiting higher awareness gains compared to their male counterparts. This aligns with recent research indicating that female preservice teachers often demonstrate greater environmental literacy and a more profound connection to nature, potentially due to socialization processes and heightened empathy toward ecological issues (Kuzu et al., 2024). Such gender disparities highlight the necessity for targeted interventions that encourage male students' engagement with environmental education.

Residence also influenced awareness gains, with urban students outperforming their rural peers. Urban environments typically offer better access to educational resources, technology, and diverse learning experiences, which can facilitate higher levels of environmental awareness (Cheng & Mao, 2024). Conversely, rural students may face challenges such as limited access to green spaces and educational materials, necessitating tailored strategies to bridge this urban-rural divide and promote equitable environmental education opportunities. The presence of family plant-based cultural practices was positively correlated with awareness gains, suggesting that familial engagement with plant-related activities fosters a deeper understanding and appreciation of plant life. This finding is consistent with studies emphasizing the importance of family involvement in environmental education, as it can enhance children's nature connectedness and environmental behaviors (Wu et al., 2023). Incorporating family-oriented programs into environmental education curricula could strengthen these connections and promote sustainable behaviors.

Family income emerged as another significant factor, with higher-income families associated with greater awareness gains. This correlation may reflect increased access to resources such as books, educational programs, and extracurricular activities that enrich students' environmental knowledge. Research indicates that socioeconomic status influences environmental attitudes and behaviors, with higher-income individuals often exhibiting more pro-environmental behaviors (Qadri et al., 2025). Addressing socioeconomic disparities is crucial for fostering inclusive environmental education that reaches all students, regardless of their economic background.

However, these patterns may not solely reflect genuine differential benefits of digital engagement. Higher scores among female and higher-income participants could also be attributed to pre-existing advantages, such as greater prior exposure to educational technologies, better access to learning materials, or higher self-efficacy in reflective learning. Thus, while the digital plant project was effective overall, further controlled studies are needed to disentangle whether such differences stem from the intervention itself or from participants' baseline conditions.

Finally, family experience with plants was positively associated with awareness gains, highlighting the value of hands-on, experiential learning in fostering environmental awareness. Engaging in activities like gardening or plant care provides practical knowledge and cultivates a sense of responsibility toward nature. Studies have shown that such experiences can enhance environmental attitudes and behaviors, particularly when they are integrated into educational settings (Stagg et al., 2024). Encouraging families to participate in plant-related activities can complement formal education and reinforce environmental stewardship. While these findings demonstrate positive effects of the digital plant project, they should be interpreted with caution due to potential response bias inherent in self-reported Likert-scale data. Participants may have provided socially desirable responses or overestimated their awareness levels after the intervention. Future research could complement self-report measures with behavioral observations or performance-based assessments to obtain a more objective representation of plant awareness.

The findings of this study indicate that sociodemographic factors, including gender, residence, family income, and family exposure to plant-related practices, significantly influence plant awareness gains among PSTs. These results have clear implications for higher education, particularly in the design and delivery of botanical education. Specifically, digital plant projects can serve as a strategic tool to bridge disparities in plant awareness arising from sociodemographic differences. By providing an inclusive, technology-supported platform for observing, documenting, and analyzing local plant diversity, such projects allow all students—regardless of gender, urban-rural background, or prior experience—to engage actively with botanical content.

To address gender disparities, botanical curricula can incorporate interactive digital assignments and collaborative projects that specifically encourage male students' participation, fostering equitable engagement and awareness gains (Almasri, 2022). The urban-rural divide can be mitigated by leveraging digital tools, virtual herbaria, and online plant databases, giving rural students access to high-quality learning experiences comparable to their urban peers (Safdar et al., 2022). Moreover, experiential learning components, such as digital documentation of plants, ethnobotanical case studies, and community-based projects, can help compensate for differences in family income and prior exposure to plants, promoting hands-on engagement that reinforces botanical knowledge and environmental stewardship (Butler et al., 2021; Stagg et al., 2024).

In practice, integrating digital plant projects into teacher education programs enables PSTs to develop not only conceptual understanding of botany but also critical awareness of biodiversity and cultural practices. Such initiatives can directly reduce plant awareness disparity by ensuring that all students, regardless of their sociodemographic background, have equal opportunities to experience, analyze, and appreciate local flora. Consequently, higher education institutions can cultivate a generation of biology teachers capable of designing inclusive, contextually relevant, and technology-enhanced botanical education, thereby addressing both cognitive and affective dimensions of plant literacy in their future classrooms.

CONCLUSION

This study examined the impact of sociodemographic factors on plant awareness gains among preservice biology teachers (PSTs) through a digital plant project aimed at bridging plant awareness disparities. The results revealed that gender, place of residence, family income, family exposure to plant-related practices, and participation in plant-based cultural activities significantly influenced awareness gains, while age showed no significant effect. Female students, urban residents, and those from higher-income families or with greater exposure to plant-related practices demonstrated higher awareness gains. The digital plant project effectively enhanced multiple dimensions of plant awareness, including attention, attitude, knowledge, and relative interest, by enabling active observation, documentation, and analysis of local flora. These findings highlight the potential of technology-supported, experiential, and project-based learning in promoting inclusive botanical education that addresses cognitive and affective aspects of plant literacy across diverse sociodemographic backgrounds. Despite these valuable insights, this study has several limitations. The sample consisted primarily of female PSTs from a limited geographic area, which may affect the generalizability of the findings.

Additionally, the study focused on short-term awareness gains without examining long-term retention or behavioral outcomes related to plant engagement. Future research should expand to more diverse populations, including longitudinal assessments, and explore additional variables such as curriculum design, teaching experience, and institutional resources. Practically, the findings suggest that higher education institutions can integrate digital plant projects, collaborative assignments, and community-based experiences to bridge gaps arising from sociodemographic differences, cultivate critical plant awareness, and prepare PSTs to implement inclusive and contextually relevant botanical education in their future classrooms.

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