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Assessing Changes in Awareness and Behavior toward Single-Use Plastic Reduction among High School Students through ArcGIS StoryMap–Based Environmental Education

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Abstract. Single-use plastics (SUPs) pose serious environmental and public health challenges, particularly in urban and school environments. This study examines how the integration of digital geospatial tools, notably ArcGIS-based StoryMaps and interactive dashboards, can enhance awareness and influence SUP-related behaviors among high school students. Conducted as a pilot at the High School for Gifted Students, Hue University of Sciences, the intervention combined baseline and post-intervention surveys, participatory mapping of plastic waste hotspots, and the implementation of a school-based waste sorting system. Changes in students' knowledge, attitudes, perceived behavioral control, and behaviors were examined using a repeated cross-sectional design, non-parametric pre–post comparisons, and post-intervention correlation analysis, grounded in the Knowledge–Attitude–Practice model and the Theory of Planned Behavior. The results indicate statistically significant improvements in key awareness indicators and modest but meaningful shifts in selected SUP-related behaviors, particularly in usage frequency and disposal practices. Post-intervention correlation patterns further suggest that attitudinal factors were more strongly associated with pro-environmental behaviors than knowledge alone, consistent with TPB assumptions. By combining spatial storytelling, interactive surveys, and dashboards, the intervention fostered higher student engagement and participation within the school community. Overall, the findings highlight the potential of GIS-based educational approaches to support sustainability-oriented learning and digital transformation in environmental education contexts in Vietnam.

Keywords: Single-use plastic; ArcGIS StoryMap; environmental education; Theory of Planned Behavior; interactive GIS

1. Introduction

Plastic is widely used worldwide, yet it poses a serious threat as a pollutant to air, land, and water. According to the Organisation for Economic Co-operation and Development, in 2021, approximately 353 million tons of plastic waste were generated globally, of which less than 10% was recycled [1]. In Vietnam, rapid economic growth and urbanization, together with major lifestyle changes, have contributed to an escalating plastic pollution crisis. The World Wide Fund for Nature (WWF) Vietnam reported that the use of single-use plastic products (SUPs) is a widespread daily practice nationwide [2].

To address this challenge, Vietnam has adopted the "National Action Plan on Ocean Plastic Waste Management to 2030," which targets a 50% reduction in marine plastic waste by 2025 and 75% by 2030. The plan includes restrictions on the production and import of single-use plastic bags beginning in 2026, with a full ban envisaged by 2031. Current policy measures emphasize minimizing SUP use, raising public awareness, promoting behavioral change in waste disposal, increasing recycling rates, and advancing a circular economy and green growth agenda [3].

In line with the goal of transforming Hue in a centrally governed city by 2025 and a model heritage city of Vietnam by 2030, the city's socio-economy development is accelarating. However, this growth poses increasing risk of plastic waste generation, particularly in the context of expanding administrative boundaries if not properly managed [3]. SUP items, such as foam containers, plastic cups, bags, and straws, are inexpensive and widely used, especially among high school students. However, their improper disposal results in long-term environmental consequences, including threats to biodiversity and contributions to climate change [2, 4].

Educating younger generations about the risks of SUPs and promoting sustainable practices is therefore essential. Nevertheless, conventional educational approaches often prove insufficient in driving meaningful and sustained behavioral change. In response, environmental organizations worldwide have increasingly adopted interactive communication methods using digital tools such as ArcGIS StoryMaps to enhance public awareness. These platforms integrate multimedia content with spatial data to contextualize environmental issues across diverse settings, including mountainous regions, schools, and coastal areas [5–7]. For example, a GIS-based project at Campion School in New Zealand enabled students to trace plastic waste along local beaches using StoryMaps, strengthening their understanding of community engagement and the relevance of the United Nations Sustainable Development Goals [8]. Similarly, Selbe et al. developed the StoryMap *Tracking Plastic Waste* to visualize pathways of plastic entering marine environments [7], while initiatives such as *Spoiled Oceans* highlight student perspectives on microplastics within food systems and aquatic ecosystems [9].

In Vietnam, the application of GIS in education has primarily focused on higher education and technical training contexts. Bui et al. [10] reviewed the integration of GIS and ArcGIS Online in teaching physics, earth science, and environmental-related modules, emphasizing GIS as an instructional support tool and a web-based learning environment. However, these applications mainly address pedagogical design and tool adoption, without systematically evaluating changes in learners' environmental awareness or behavior using quantitative methods or established behavioral frameworks. Consequently, empirical evidence on the effectiveness of GIS-based storytelling and interactive spatial platforms in shaping environmental awareness and behavior among high school students in Vietnam remains limited.

With the rise of Industry 4.0 technologies, the Vietnamese's digital transformation agenda, and the digital fluency of Gen Z, integrating interactive tools into environmental education is both timely and necessary. ArcGIS StoryMaps provide a dynamic platform for creating cartographic narratives that combine maps, text, and visual media to effectively convey environmental issues [6]. These tools have shown promise in raising awareness and promoting responsible behavior among high school students.

However, empirical assessments that combine pre–post statistical testing and behavioral correlation analysis to evaluate the educational impacts of StoryMap-based interventions remain limited. By integrating ArcGIS StoryMap with participatory surveys, dashboards, and a school-based waste-sorting model, this study provides one of the first quantitative evaluations of GIS-based environmental education in Vietnam, grounded in the Knowledge–Attitude–Practice framework and the Theory of Planned Behavior.

Building on this context, this study quantitatively assesses changes in high school students' knowledge, attitudes, perceived behavioral control, and behaviors related to single-use plastic reduction through an ArcGIS StoryMap–based educational intervention, grounded in the Knowledge–Attitude–Practice framework and the Theory of Planned Behavior.

The study advances GIS-based environmental education research by providing one of the first quantitative evaluations of an ArcGIS StoryMap–based intervention targeting single-use plastic reduction among high school students in Vietnam. By integrating repeated cross-sectional pre–post testing with non-parametric statistical analysis and post-intervention correlation modeling, the research moves beyond descriptive applications to empirically examine how geospatial storytelling relates to changes in environmental awareness and behavior. The findings contribute new evidence on the role of interactive GIS platforms in linking knowledge, attitudes, and practices within a secondary education context.

2. Data and methodology

2.1 Study design and research framework

This study is rooted in the Knowledge - Attitude - Practice (KAP) model and the Theory of Planned Behavior (TPB) to assess how digital interventions influence environmental behavior among students. The KAP model assumes a step-by-step process in which the acquisition of knowledge leads to positive attitudes, which in turn drive behavioral change [11]. This framework guided the survey design and supported the interpretation of pre–post changes in students' awareness and self-reported practices related to single-use plastic (SUP) reduction after engaging with the ArcGIS StoryMap.

Meanwhile, the TPB offers a broader perspective by including not only attitudes but also perceived social norms and perceived behavioral control as predictors of behavioral intention [12]. In the school context, students' behavior is influenced not only by individual understanding but also by peer influence and practical constraints, such as the availability of recycling bins or reusable alternatives.

Accordingly, TPB constructs were operationalized through survey indicators capturing attitude, perceived behavioral control, and observed behavioral outcomes, and were subsequently examined using post-intervention correlation analysis. Accordingly, TPB constructs were operationalized through survey indicators capturing attitude, perceived behavioral control, and observed behavioral outcomes, and were subsequently examined using post-intervention correlation analysis.

This study combined spatial storytelling with real-world practices, such as waste sorting and hotspot mapping, to translate awareness into tangible actions, thereby improving the effectiveness of environmental education. Rather than treating digital tools as standalone communication products, the intervention integrated interactive GIS applications with physical infrastructure and participatory activities, enabling students to connect abstract environmental concepts with their daily school environment.

The overall methodological workflow is summarized in Figure 1, illustrating the sequential integration of an ArcGIS-based educational intervention with non-parametric statistical analyses. The study began with the establishment of research objectives and theoretical grounding in the Knowledge–Attitude–Practice framework and the Theory of Planned Behavior, followed by the development of a survey instrument using ArcGIS Survey123. Survey responses were subsequently processed and visualized through ArcGIS Web Maps and Dashboards to capture both spatial patterns and descriptive indicators of students' awareness and behaviors. In parallel, a school-based waste-sorting model and hotspot mapping activities were implemented to generate contextualized field data and encourage student participation. All components were finally consolidated into an interactive ArcGIS StoryMap hosted on the ArcGIS Online platform, serving as an integrated environment for communication, engagement, and post-intervention analysis rather than as a causal mechanism for behavioral change [6,7,13]. Methodological workflow integrating ArcGIS-based educational tools with the Knowledge–Attitude–Practice (KAP) model and the Theory of Planned Behavior (TPB) to assess changes in students' awareness and behaviors related to single-use plastic reduction. Dashed lines represent statistical associations rather than causal relationships.

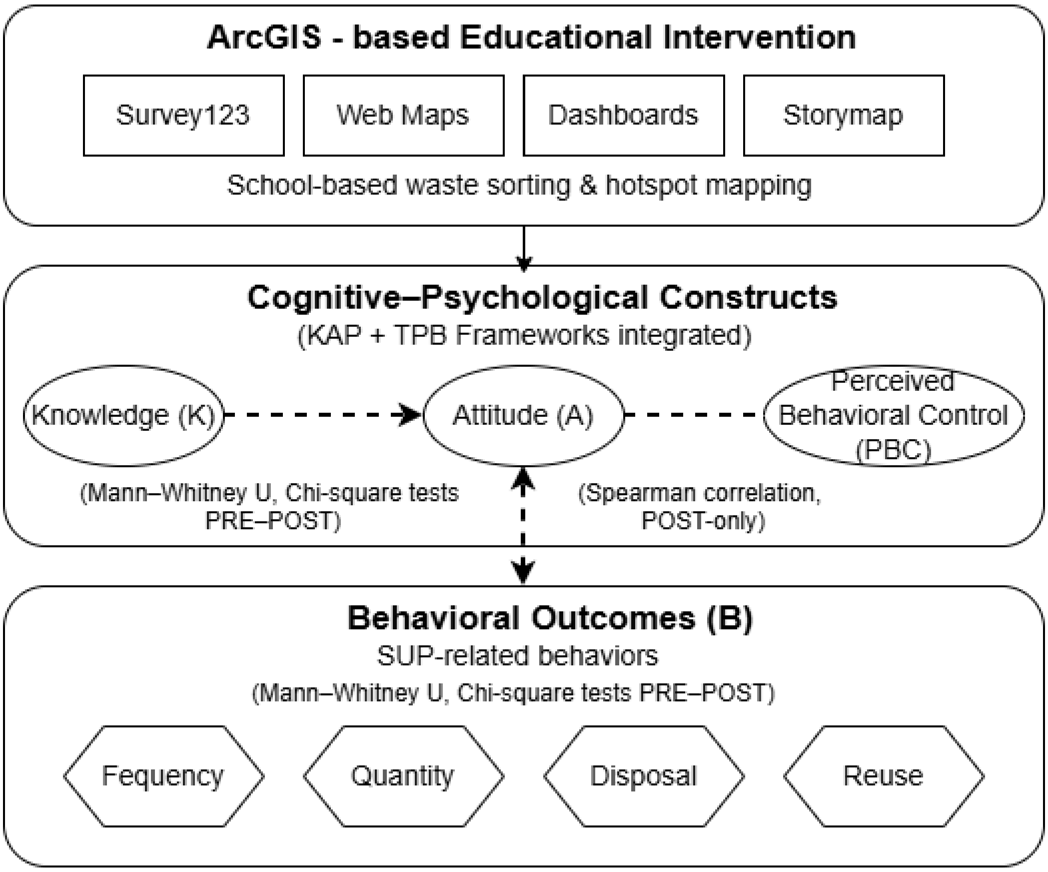


Figure 1. Research framework integrating ArcGIS-based intervention and TPB constructs

2.2 Study area and participants

The study was conducted at the High School for Gifted Students, Hue University of Sciences (HUSC High School), Hue City, Vietnam, where increasing plastic consumption poses growing environmental pressures in the context of urban development [14,15]. The school provides an appropriate setting for piloting GIS-based environmental education among digitally literate Generation Z students with regular access to smartphones and internet-enabled learning tools.

The study population comprised 374 students in the 2022–2023 academic year. The minimum sample size was estimated using Yamane's (1967) formula with a 10% margin of error (n = 79), with a 10% contingency added to account for non-response, resulting in a target of approximately 87 students per survey round [16]. Data were collected using a repeated cross-sectional design. The pre-intervention (PRE) and post-intervention (POST) surveys yielded 81 and 85 valid responses, respectively. As the samples were not fully matched, they were treated as independent cross-sections with comparable characteristics, appropriate for non-parametric statistical analysis.

2.3 Data collection and spatial data generation

2.3.1. Survey data

Survey data were collected using ArcGIS Survey123 and administered before (PRE) and after (POST) the educational intervention. The questionnaires captured students' knowledge of SUP impacts, attitudes toward plastic reduction, perceived behavioral control, and self-reported behaviors. All survey responses were anonymous and voluntary.

Importantly, no personal residential locations or identifiable individual tracking data were collected. Survey responses were linked only to categorical variables (e.g., grade level) and optional spatial inputs related exclusively to school-based activities, ensuring respondent privacy.

The Survey123 instrument was designed as a mobile-compatible, spatially enabled questionnaire [6,7] and structured around three main themes: (1) Knowledge and awareness of SUPs, including decomposition time, environmental impacts, and understanding of 3R/3T principles; (2) Behavioral practices, such as types of SUPs used, frequency of use, disposal methods, and reuse or recycling behaviors; and (3) Student perspectives on practical solutions and communication strategies for reducing SUP consumption within the school environment. Basic demographic information (e.g., grade level) was also collected.

Data collection was conducted in two stages following a repeated cross-sectional design. The PRE survey established baseline awareness and behaviors, while the POST survey was administered after the implementation of educational interventions, including the ArcGIS StoryMap, quizzes, participatory mapping activities, and a school-based waste-sorting model. As individual identifiers were not used, the PRE and POST samples were treated as independent cross-sections with comparable characteristics, which is appropriate for non-parametric statistical analysis. In addition to survey responses, secondary data were extracted from the ArcGIS StoryMap platform, including page views and interactions with embedded content. These metrics were used to assess student engagement and the dissemination potential of the digital intervention, complementing the primary survey data.

2.3.2. Spatial data and SUP hotspot mapping

Spatial data were generated through participatory mapping activities embedded in the Survey123 instrument and classroom exercises. Students were asked to identify locations within the school environment where SUP use, accumulation, or disposal was frequently observed, such as canteens, corridors, classrooms, and common areas.

The resulting spatial points represent perceived SUP hotspots, reflecting students' awareness and observations rather than statistically derived density-based hotspots. Accordingly, these points were visualized as discrete features in ArcGIS Web Maps and Dashboards for exploratory, educational, and communicative purposes, supporting spatial discussion and storytelling rather than formal hotspot or clustering analysis. This approach aligns with the study's educational objectives and avoids misinterpretation of the mapped points as quantitative spatial intensity measures.

2.4 Educational intervention and digital tools

To promote experiential learning and support behavioral change, a pilot waste-sorting system was implemented at HUSC High School. The system comprised three color-coded bins for organic, recyclable, and residual waste, strategically placed at key locations across the campus. Clear signage and operational guidance were provided to support accurate waste classification by students. This initiative aligned with national guidelines on integrating environmental practices into educational settings [2]. Feedback collected during the pilot phase was used to refine bin placement and instructions, and also informed the design of subsequent survey items and digital storytelling content.

A GIS-integrated educational workflow was employed to enhance spatial engagement and environmental literacy. Using smartphones, students participated in identifying and mapping locations within the school where single-use plastic (SUP) use or accumulation was frequently observed. These participatory inputs were visualized in ArcGIS Web Maps and connected to ArcGIS Dashboards, enabling real-time visualization of perceived SUP distribution patterns and aggregated survey indicators. This participatory GIS approach emphasized students' roles as contributors to spatial knowledge rather than passive recipients, reinforcing spatial thinking and place-based environmental awareness.

The intervention culminated in the development of an ArcGIS StoryMap, a web-based narrative platform increasingly applied in environmental education [7, 17, 18]. The StoryMap integrated multiple data streams, including survey responses (ArcGIS Survey123), spatial layers (ArcGIS Web Maps), dashboards (for aggregated analytics), and multimedia elements such as images, infographics, videos, and quizzes. The development process followed a four-step sequence: (1) survey design and data collection via ArcGIS Survey123; (2) spatial visualization using ArcGIS Web Maps; (3) creation of interactive dashboards for summary analytics; and (4) integration of all components into a cohesive StoryMap narrative. By combining spatial visualization with digital storytelling, the intervention supported inquiry-based learning, critical reflection, and student-centered engagement with SUP-related issues.

Quantitative and qualitative information on SUP awareness, behaviors, and perceived reduction strategies was derived from Survey123 responses and participatory mapping outputs. These data were processed and visualized through a suite of GIS-based applications. ArcGIS Survey123 enabled structured mobile data collection and seamless integration of attribute and spatial information [6, 7], while ArcGIS Dashboards provided aggregated, real-time summaries of awareness indicators and reported behaviors. All outputs were embedded within the ArcGIS StoryMap, which functioned as the central platform for educational communication and outreach. Previous studies have highlighted the effectiveness of StoryMap-based approaches in promoting spatial literacy and engagement among high school students [7, 17, 18].

To extend the reach of the intervention, the StoryMap was disseminated through multiple channels, including the school website, social media platforms, and public environmental events such as the “Open Day” at Hue University of Sciences. Peer-to-peer sharing among student groups further facilitated dissemination beyond the immediate school context. Interactive elements, including quizzes and multimedia content, were incorporated to sustain engagement and reinforce key learning messages [17, 18].

2.5. Variable construction and statistical analysis

2.5.1. Variable construction and measurement

Based on the Knowledge–Attitude–Practice (KAP) framework [11] and the Theory of Planned Behavior (TPB) [12], survey variables were organized into four analytical constructs: Knowledge (K), Attitude (A), Perceived Behavioral Control (PBC), and Behavior (B) related to single-use plastic (SUP) reduction.

Knowledge variables captured students’ factual understanding of SUP issues, including perceived decomposition time of plastic waste, awareness of environmental and health impacts, and understanding of the 3R/3T principles. Attitudinal variables reflected students’ evaluative orientations toward reducing SUP use and supporting environmentally responsible practices. Perceived behavioral control variables assessed students’ self-reported confidence and perceived ability to reduce SUP consumption within the school context, considering practical constraints and available facilities. Behavioral variables represented self-reported practices, including frequency of SUP use, quantity of SUP products used per day, and disposal or handling methods. Most survey items were measured using ordinal or nominal scales, consistent with common practice in KAP-based and educational behavioral research [11]. Given the heterogeneous scaling and the exploratory nature of the study, individual items were analyzed directly rather than aggregated through parametric latent variable modeling. To support post-intervention interpretation within the TPB framework, composite indices (K_score, A_score, PBC_score, and B_score) were additionally constructed using normalized item means. Each component variable was first rescaled to a 0–1 range using min–max normalization to ensure comparability across different measurement scales. Composite scores were then calculated as the arithmetic mean of the normalized items within each construct. This approach preserves relative variation while avoiding distributional assumptions, and is appropriate for exploratory behavioral analysis in small samples [12, 13]. Table 1 summarizes the survey variables, coding schemes, and measurement scales corresponding to the Knowledge–Attitude–Practice (KAP) and Theory of Planned Behavior (TPB) constructs used in this study.

Table 1. Operationalization of KAP–TPB variables and measurement scales

TPB/KAP domain	Variable	Description	Coding	Scale
Knowledge (K)	K1_decomp	Perceived decomposition time of SUP waste	1 = <100 yrs; 2 = 100–500 yrs; 3 = >500 yrs	Ordinal
	K2_impact	Knowledge of harmful effects of SUPs	0 = No/Don’t know; 1 = Yes	Nominal
	K3_3R3T	Correct understanding of 3R/3T	0 = Incorrect/Don’t know; 1 = Correct	Nominal
Attitude (A)	A1_green	Willingness to use green alternatives	0 = Hesitant/Not willing; 1 = Willing	Nominal
	A2_change	Willingness to change habits	0 = No/Not concerned; 1 = Yes	Nominal
Perceived Behavioral Control (PBC)	PBC1_sortAware	Awareness of waste classification at school	0 = No/Not aware; 1 = Yes	Nominal
	PBC2_volunteer	Willingness to participate as hotspot volunteer	0 = No; 1 = Yes	Nominal
Behavior (B)	B1_freq	Frequency of SUP consumption	1 = Normal; 2 = Frequent; 3 = Very frequent	Ordinal
	B2_qty	Number of SUP products per day	1 = ≤1; 2 = 1–3; 3 = >3	Ordinal
	B3_disposal	Disposal/handling of used SUPs	1 = Discard; 2 = Collect; 3 = Reuse	Ordinal
	B4_reuseEver	Ever recycled/reused SUPs	0 = No; 1 = Yes	Nominal

2.5.2. Statistical analysis

Statistical analyses were conducted to examine changes between the pre-intervention (PRE) and post-intervention (POST) surveys, as well as relationships among TPB constructs in the post-intervention dataset. Because the survey items were primarily ordinal or nominal and the PRE and POST samples were treated as independent repeated cross-sections, non-parametric statistical tests were applied. Differences between PRE and POST groups for key knowledge and behavioral indicators were assessed using the Mann–Whitney U test for ordinal variables and the Chi-square test of independence for categorical variables. These tests are appropriate for non-normally distributed data and unequal group sizes, and are widely used in educational and behavioral research [12, 16].

To examine theoretical relationships among constructs within the TPB framework, Spearman’s rank correlation analysis was performed using POST-only data. This approach avoids conflating intervention effects with correlational structure and allows assessment of monotonic associations among Knowledge, Attitude, Perceived Behavioral Control, and Behavior after exposure to the educational intervention [12]. Correlation coefficients (ρ) and two-tailed significance levels were reported, with statistical significance evaluated at $p < 0.05$. All statistical analyses were conducted using standard statistical software. Given the pilot nature of the study and its focus on exploratory evaluation, effect sizes and causal inference were not emphasized.

The combined use of item-level non-parametric testing and post-intervention correlation analysis enabled a balanced evaluation of both intervention-related changes and theoretical relationships among behavioral constructs. This analytical strategy aligns with prior applications of KAP surveys in environmental education [11] and with the Theory of Planned Behavior's emphasis on attitudinal and perceived control pathways influencing behavior [12]. The approach is suitable for small-scale, school-based interventions where matched longitudinal data are not available and where interpretability and methodological transparency are prioritized.

3. Results

3.1 Baseline characteristics and pre-intervention awareness (PRE survey)

The pre-intervention survey (PRE) provides an overview of baseline characteristics, awareness, and behaviors related to single-use plastic (SUP) consumption among high school students prior to the educational intervention. A total of 81 valid responses were obtained, representing approximately 10% of the total student population at Hue University of Sciences High School for Gifted Students. Most respondents resided in urban or peri-urban areas of Hue City, reflecting the school's location and daily consumption context (Figure 2).

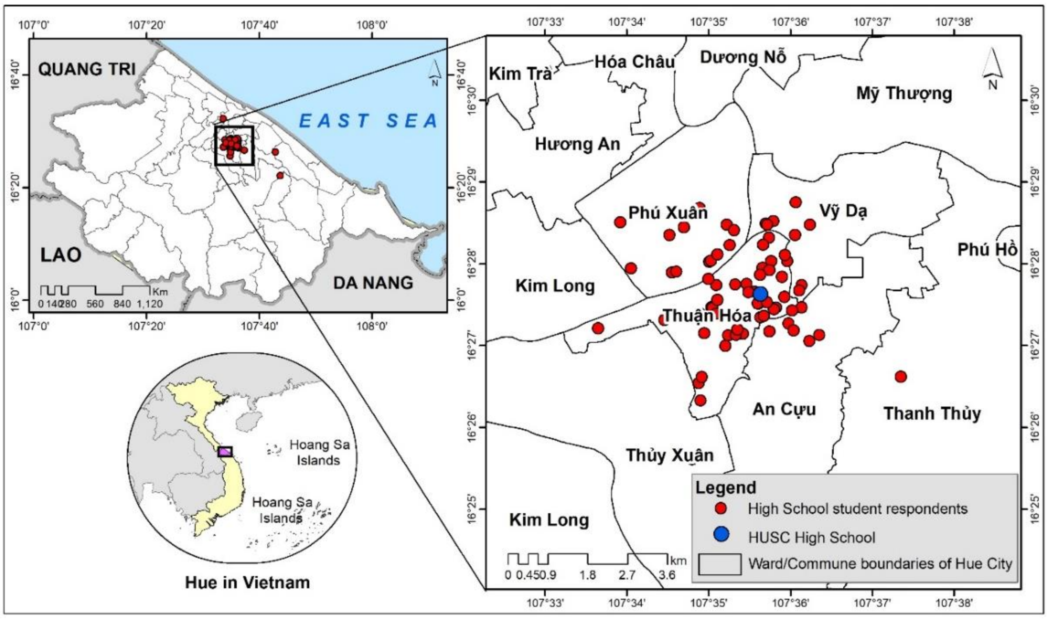


Figure 2. Spatial distribution of HUSC high school student respondents in Hue City.

Baseline conditions were summarized using composite indices corresponding to the Knowledge (K), Attitude (A), and Behavior (B) domains of the KAP and TPB frameworks. For each respondent, domain scores were calculated by aggregating normalized item responses within each construct, allowing for a standardized comparison across domains. The resulting radar chart (Figure 3) illustrates the relative baseline levels of knowledge, attitudes, and self-reported behaviors toward SUP reduction. Scores were normalized to a 0–1 scale and visualized using a radar chart to illustrate relative baseline differences across domains.

Figure 3. Baseline composite scores of knowledge (K), attitude (A), and behavior (B) related to single-use plastic reduction among high school students (PRE survey, n = 81).

Figure 3 provides a disaggregated view of individual knowledge, attitude, and behavior indicators underlying the composite K–A–B scores. The detailed distributions are presented to illustrate specific misconceptions, usage patterns, and behavioral constraints observed prior to the intervention.

Overall, students demonstrated a relatively high attitudinal readiness toward reducing SUP use, as reflected by a high mean A_score. A majority of respondents expressed willingness to use environmentally friendly alternatives and indicated positive intentions to change consumption habits. In contrast, baseline knowledge levels were moderate. While many students recognized the long decomposition time of plastic waste and acknowledged its environmental and health impacts, understanding of specific concepts such as the 3R/3T framework and waste classification remained uneven.

Actual behavioral practices exhibited the lowest composite score among the three domains. Despite favorable attitudes, daily SUP consumption was still common, particularly for food and beverage packaging. Many students reported frequent use of foam containers, plastic bags, and single-use cups, largely driven by convenience and the limited availability of alternatives. Post-use handling practices were also mixed, with a substantial proportion of SUPs being discarded without separation, indicating limited translation of awareness into routine behavior.

The radar chart highlights a clear baseline gap between awareness and action: attitudes toward SUP reduction were substantially higher than both knowledge and self-reported behaviors, with behavior lagging most noticeably. This pattern suggests that, prior to the intervention, positive environmental intentions had not yet been consistently translated into everyday practices. These baseline findings provide a critical reference point for evaluating the effects of the subsequent GIS-based educational intervention and support the application of non-parametric pre–post statistical testing and TPB-informed analysis in the following sections.

3.2 Pre–post changes in awareness, attitudes, perceived behavioral control, and behavior

To evaluate changes associated with the educational intervention, pre- and post-survey responses were compared using a combination of non-parametric and categorical statistical tests. Given the repeated cross-sectional design and the ordinal or nominal nature of most variables, Mann–Whitney U tests were applied to ordinal indicators, while Chi-square tests of independence were used for binary categorical variables.

3.2.1. Mann–Whitney U test results for ordinal indicators

Mann–Whitney U tests revealed statistically significant differences between PRE (n = 81) and POST (n = 85) survey rounds for selected ordinal indicators (Table 2).

Table 2. Mann–Whitney U test results for PRE–POST comparisons of SUP-related indicators

Variable	Survey round	Mean rank	Mann–Whitney U	Z	*p*-value
Perceived decomposition time of SUP waste	PRE	72.34	2538.5	−3.283	0.001
	POST	94.14			
Frequency of SUP consumption	PRE	90.28	2893.5	−2.160	0.031
	POST	77.04			
Number of SUP products per day	PRE	87.6	3110.5	−1.317	0.188
	POST	79.59			
Disposal/handling of used SUPs	PRE	81.08	3246.5	−0.680	0.497
	POST	85.81			

(PRE survey, n = 81; POST surve, n=85)

Mann–Whitney U tests identified significant PRE–POST differences for perceived plastic decomposition time ($U = 2538.5$, $Z = -3.283$, $p = 0.001$) and frequency of SUP consumption ($U = 2893.5$, $Z = -2.160$, $p = 0.031$), indicating improved awareness and a modest reduction in reported usage frequency after the intervention. No significant differences were observed for daily consumption quantity or disposal practices, suggesting that short-term interventions primarily influenced cognitive perceptions rather than more habitual behaviors..

3.2.2. Chi-square test results for categorical indicators

Chi-square analyses further clarified pre- and post-intervention differences across Knowledge, Attitude, Perceived Behavioral Control (PBC), and Behavior domains (Table 3).

Table 3. Chi-square test results for PRE–POST comparisons of categorical SUP-related indicators

TPB/KAP domain	Variable	χ^2	df	*p*-value	Effect size (Φ / V)	Direction of change (POST vs PRE)
Knowledge	Knowledge of harmful effects of SUPs	0.829	1	0.363	0.071	No significant change
	Correct understanding of 3R/3T	21.833	1	<0.001	0.363	↑ Correct understanding
Attitude	Willingness to use green alternatives	1.433	1	0.231	0.093	No significant change
	Willingness to change habits	8.3	1	0.004	0.224	↓ Hesitant / Not concerned
PBC	Awareness of waste classification	21.17	1	<0.001	0.357	↑ Awareness
	Willingness to be hotspot volunteer	3.961	1	0.047	0.154	↑ Participation
Behavior	Ever recycled / reused SUPs	0.181	1	0.671	0.033	No significant change

Within the knowledge domain, correct understanding of the 3R/3T framework increased markedly after the intervention ($\chi^2 = 21.83$, $p < 0.001$, $\Phi = 0.36$), while awareness of the harmful effects of SUPs showed no significant change, indicating relatively high baseline awareness.

Attitudinal readiness to change SUP-related habits also improved significantly ($\chi^2 = 8.30$, $p = 0.004$, $\Phi = 0.22$), whereas willingness to adopt environmentally friendly alternatives did not differ between survey rounds. In the perceived behavioral control domain, awareness of waste classification at school

increased substantially ($\chi^2 = 21.17$, $p < 0.001$, $\Phi = 0.36$), accompanied by a modest rise in willingness to participate as hotspot volunteers ($\chi^2 = 3.96$, $p = 0.047$).
By contrast, no significant PRE–POST differences were observed for self-reported recycling or reuse behaviors. Overall, the results indicate that the intervention primarily strengthened students' knowledge, attitudes, and perceived behavioral control, while short-term behavioral change remained limited, consistent with the staged progression proposed by the KAP model and the Theory of Planned Behavior.

3.3. School-based waste sorting model

A three-bin waste-sorting system was introduced at HUSC High School to support SUP-reduction behaviors. Prior to implementation, only 59% of students reported awareness of waste classification practices, reflecting the lack of structured infrastructure. Bins were installed at locations identified through student-generated SUP hotspot mapping and visualized using ArcGIS Web Maps and Dashboards (Fig. 4). SUP "hotspots" shown in Fig,4 (d) represent perceived accumulation points reported by students through participatory mapping activities, rather than statistically derived density-based hotspots. These locations were used for educational visualization and bin placement guidance.

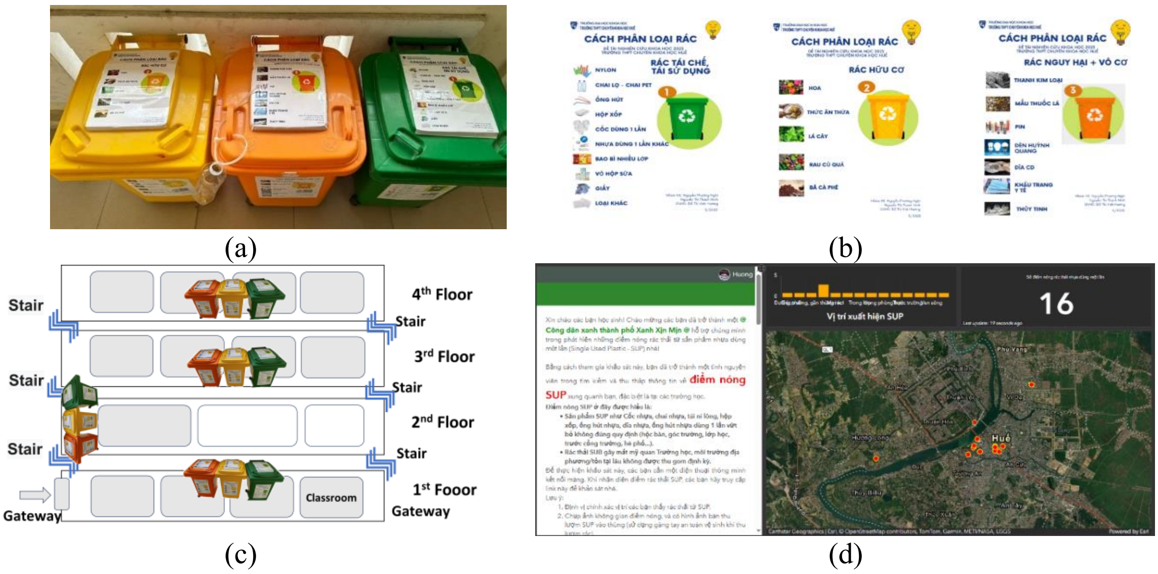


Figure 4. School-based waste-sorting model and GIS educational tools: *(a)* three-bin *sorting systems, (b) Posters for recycling education and waste classification, (c) Waste bin placement (d) Real-time dashboard and map displaying SUP hotspots generated from student surveys.*

Weekly monitoring using a semi-quantitative scheme (x: <50%, o: 50–79%, O: ≥80% correct sorting) showed a gradual improvement from predominantly non-compliant behavior to consistent high compliance across all school floors by December 2023 (Table 4). The shift from non-compliance to moderate compliance occurred within approximately 4–6 weeks after installation.

While the waste-sorting model provided a physical and behavioral context for SUP reduction within the school environment, its effectiveness was closely linked to students' engagement with the accompanying GIS-based digital tools. The following section therefore examines how ArcGIS StoryMap, dashboards, and participatory mapping activities supported learning engagement and awareness beyond the physical intervention.

Table 4. Timeline-based Semi-quantitative assessment of waste-sorting compliance at HUSC High School (May–December 2023) by school floor (May–December 2023)

Month	Day/ Week	High School Building floor			
		1st	2nd	3rd	4th
May (15-20/5/2023)	Mon	x	x		
	Tue	x	x		
	Wed	x	x		
	Thu	x	x		
	Fri	o	o		
	Sat	o	x		
September 2023	Week 1	x	x	x	x
	Week 2	x	o	x	x
	Week 3	x	o	x	o
	Week 4	o	o	o	o
October 2023	Week 1	o	o	o	o
	Week 2	o	o	o	o
	Week 3	o	o	o	o
	Week 4	o	o	o	o
Decmeber 2023	Week 1	o	O	o	o
	Week 2	o	O	o	o
	Week 3	O	O	O	O
	Week 4	O	O	O	O

The results reveal a moderate and statistically significant positive correlation between Attitude and Behavior (ρ = 0.335, p= 0.002), indicating that students with more favorable attitudes toward reducing SUP use tended to report more pro-environmental behaviors. This finding highlights attitude as a key determinant of behavioral engagement in the post-intervention context.

In addition, Attitude was positively associated with Perceived Behavioral Control (ρ = 0.258, p = 0.017), suggesting that students who held more positive attitudes also perceived greater ability or confidence to reduce SUP consumption. However, no significant association was observed between Perceived Behavioral Control and Behavior (ρ = 0.096, p = 0.382), implying that perceived capacity alone was insufficient to translate into actual behavioral change during the study period.

Regarding knowledge, Knowledge score exhibited a weak but statistically significant negative correlation with Behavior (ρ = –0.235, p = 0.030), while showing no significant relationship with either Attitude or Perceived Behavioral Control. This pattern likely reflects a ceiling effect in post-intervention knowledge, where knowledge levels were uniformly high and thus no longer served as a differentiating factor influencing behavior.

Overall, the correlation structure suggests that, following the intervention, attitudinal factors played a more prominent role in shaping SUP-related behaviors than knowledge or perceived control, consistent with the central propositions of the Theory of Planned Behavior.

3.4 Educational StoryMap as a learning tool

A key output of the intervention was the development of an ArcGIS StoryMap that integrated survey results, student-generated spatial data, and interactive media into a single digital platform supporting SUP awareness and engagement. The StoryMap consolidated data collected through ArcGIS Survey123, Web Maps, and Dashboards, as described in Sections 2.4 (Figure 5).

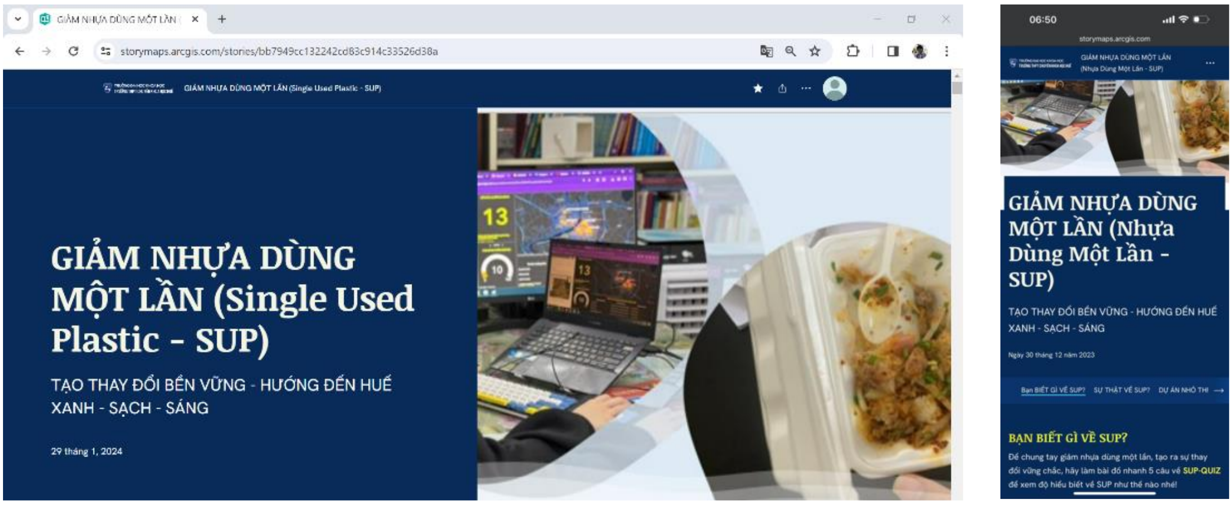
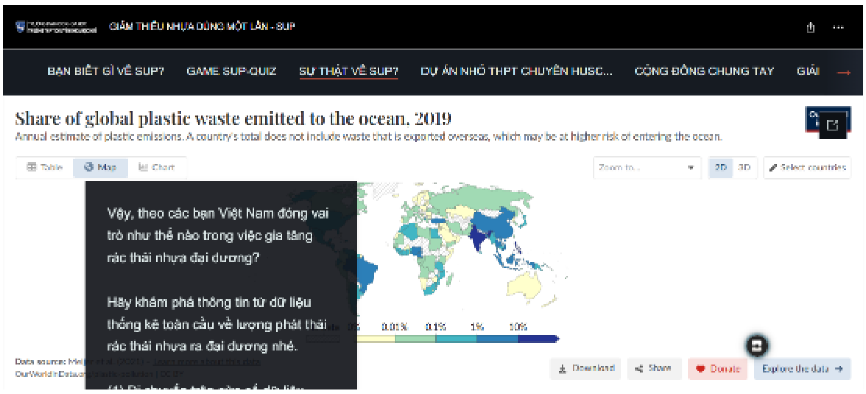


Figure 5. ArcGIS StoryMap interface displayed on desktop and smartphone devices.

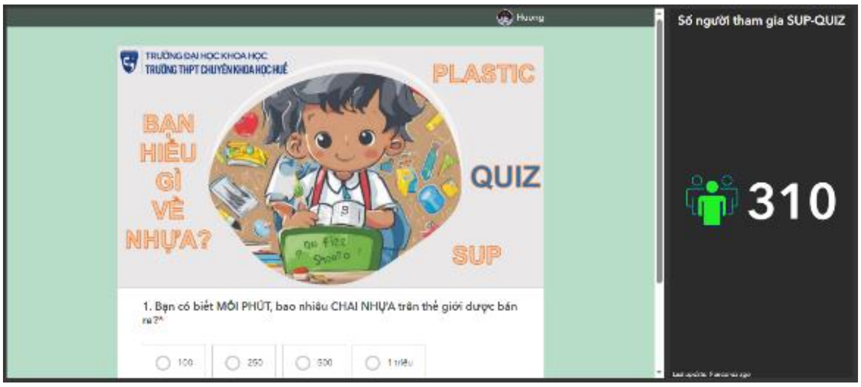
Usage analytics extracted from the ArcGIS StoryMap indicate substantial engagement with the platform. During the implementation period, the StoryMap recorded 2,619 views, including 310 interactions with embedded learning activities such as quizzes and surveys. These metrics suggest a high level of student participation in the digital components of the intervention.

Participatory mapping features embedded in the StoryMap enabled students and external stakeholders to contribute spatial information related to SUP reduction. A total of 21 information points on plastic-reduction alternatives (e.g., cafés offering incentives for reusable containers) and 6 student-identified locations requiring cleanup were submitted and visualized through ArcGIS Dashboards. These user-generated data were displayed in real time, providing spatial feedback on community engagement and perceived SUP accumulation points.

The StoryMap also incorporated a reflection component in which students completed a follow-up survey after interacting with the digital content. Comparative dashboard outputs showed population-level shifts in awareness and self-reported behavioral intentions, consistent with the statistical results presented in Sections 3.2 and 3.5. Together, these outputs demonstrate the capacity of GIS-based storytelling to support interactive participation and data-driven reflection in a school-based environmental education context.



(a)



(b)

Figure 6. Interactive ArcGIS StoryMap components to support SUP awareness and reduction: (a) Explore Global data visualization on plastic waste flows from OurWorldinData.org; (b) Interactive QUIZ-SUP game.

3.5. Relationships among Knowledge, Attitude, Perceived Behavioral Control, and Behavior (POST survey)

Spearman's rank correlation analysis was conducted using post-intervention data (n = 85) to examine associations among composite indices of Knowledge (K_score), Attitude (A_score), Perceived Behavioral Control (PBC_score), and Behavior (B_score) related to single-use plastic (SUP) reduction (Table 5).

Table 5. Spearman rank correlations among TPB constructs in the POST survey

	K_score	A_score	PBC_score	B_score
K_score	1			
A_score	-0.015	1	.258*	.335**
PBC_score	-0.055	.258*	1	0.096
B_score	-.235*	.335**	0.096	1

POST-only, N = 85, *p < 0.05; ** p < 0.01.

Attitude showed a moderate and statistically significant positive correlation with Behavior ($\rho = 0.335$, $p = 0.002$), indicating that students with more favorable attitudes toward SUP reduction tended to report more pro-environmental behaviors. Attitude was also positively associated with Perceived Behavioral Control ($\rho = 0.258$, $p = 0.017$). In contrast, no significant correlation was observed between Perceived Behavioral Control and Behavior ($\rho = 0.096$, $p = 0.382$). Knowledge exhibited a weak but statistically significant negative correlation with Behavior ($\rho = -0.235$, $p = 0.030$) and showed no significant association with Attitude or Perceived Behavioral Control. Overall, the correlation structure indicates that, in the post-intervention context, attitudinal factors were more strongly associated with SUP-related behaviors than knowledge or perceived control.

4. Discussions

This study contributes to the advancing field of environmental and sustainability education by illustrating the integration of digital geospatial technologies, specifically ArcGIS StoryMap as a viable strategy for fostering place-based awareness, ecological literacy, and behavioral engagement among students. In the context of growing concerns about SUP waste, particularly in Vietnam's urban areas, school-based interventions that combine digital and physical components offer both pedagogical and practical benefits. As high school students interacted with spatial content and story elements, their willingness to reuse SUPs or dispose of them correctly increased. These findings align with prior studies on GIS-based pedagogy and support the role of digital storytelling in promoting pro-environmental attitudes among Gen Z learners [8, 17, 18]. The approach demonstrated strong adaptability to educational settings and offers a scalable model for integrating spatial literacy, ICT, and sustainability education in school contexts. These findings are consistent with research on GIS-based environmental education, which emphasizes that interactive digital media can significantly influence high school students' environmental attitudes and behavior [17]. Beyond demonstrating a practical educational intervention, the study provides empirical evidence on how GIS-based storytelling can operationalize behavioral theory within a school-based environmental education setting.

The observed behavioral shifts align with established theories of behavior change, particularly the KAP framework and the TPB. According to KAP, knowledge acquisition leads to attitude formation, which in turn can drive behavior change [11]. These observed changes were statistically examined using non-parametric tests to account for the repeated cross-sectional design. Mann–Whitney U tests revealed a significant improvement in students' perceived decomposition time of SUP waste ($p < 0.01$), while Chi-square analyses indicated a marked increase in correct understanding of the 3R/3T framework after the intervention ($p < 0.001$). The use of non-parametric tests strengthens the robustness of these findings by accounting for ordinal measurement scales and the repeated cross-sectional design.

In this study, high school students demonstrated enhanced understanding of SUP decomposition timelines and associated health-environmental risks, which correlated with improved attitudes toward green consumption and recycling. These cognitive gains were reflected in increased willingness to reuse plastic products and participate in waste-sorting activities. TPB further explains this process by emphasizing the interplay between behavioral intentions, subjective norms, and perceived behavioral control [12]. In our context, interventions such as StoryMap-based learning and peer-generated dashboards enhanced high school students' perceived control and awareness of environmental norms within their school community.

From a TPB perspective, the use of interactive StoryMaps and integrated dashboards likely enhanced students' perceived behavioral control by transforming abstract environmental issues into tangible, localized, and actionable spatial information. By visualizing SUP hotspots, waste-sorting locations, and peer-generated data, the intervention reduced cognitive distance between knowledge and action and increased students' confidence in their ability to engage in pro-environmental practices. This interpretation is consistent with the concept of *geo-enablement*, whereby geospatial technologies support learning not only through information delivery but also by empowering users to understand, evaluate, and act upon real-world environmental challenges (Kerski, 2015) [19]. Similar studies have shown that participatory mapping and spatial feedback mechanisms can strengthen learners' sense of agency and environmental responsibility, particularly in place-based educational contexts. In this study, such geo-enablement was reflected in increased post-intervention perceived behavioral control and participatory engagement, as evidenced by both survey responses and user-generated spatial contributions.

The visible presence of labeled bins, spatial feedback maps, and peer-led activities reinforced the subjective norms that support pro-environmental behaviors. However, consistent with findings from other educational interventions [19], the study also reveals the limitations of short-term digital engagement in achieving sustained behavioral transformation.

This pattern is further supported by the post-intervention correlation analysis, which showed that knowledge was weakly and negatively associated with behavior, while attitude exhibited a moderate positive correlation with behavioral outcomes. This finding aligns with the well-documented "knowledge–behavior gap" in environmental education, whereby increased knowledge alone does not necessarily translate into pro-environmental action. As noted by Kollmuss and Agyeman (2002), environmental behavior is shaped by a complex interplay of internal factors (such as attitudes, values, and motivation) and external constraints, and once a basic level of awareness is achieved, attitudinal and contextual factors tend to play a more decisive role than knowledge in driving actual behavior [20]. In this study, the results suggest that the intervention primarily influenced behavioral outcomes through attitudinal change rather than through further gains in factual knowledge. In this study, such geo-enablement was reflected in increased post-intervention perceived behavioral control and participatory engagement, as evidenced by both survey responses and user-generated spatial contributions.

Although daily usage of SUPs showed a slight decline, the persistence of habitual consumption patterns, due to factors such as lack of convenient alternatives and inconsistent institutional reinforcement, highlights the need for structural interventions and curriculum integration. This is supported by WWF's "Huế – Urban Plastic Reduction" project, which emphasizes a three-pronged approach of behavior change, infrastructure support, and community-based communication [21, 22, 23]. The outcomes from this pilot are consistent with international findings. Pyne et al. (2022) demonstrated that participatory StoryMaps can enhance environmental awareness and cultural connection through geospatial narratives, particularly in educational contexts [18]. This study thus contributes to the growing body of work that highlights how spatial technology and digital engagement, when localized and paired with supportive infrastructure, can promote pro-environmental behaviors. As noted by Pyne et al. (2022), participatory mapping and storytelling foster deeper environmental awareness by connecting learners with real-world places and problems [18]. Our intervention, although modest in scale, offers a replicable and scalable model to complement broader initiatives, such as the WWF project, and advance Sustainable Development Goals (SDG)-aligned environmental education in Vietnam and beyond [21]. While the findings are context-specific, the underlying design principles—combining spatial feedback, digital storytelling, and school-based infrastructure—are transferable to similar urban educational settings.

Despite notable success in terms of awareness and participation, several challenges remain. Not all high school students had access to mobile devices, and some initially showed disinterest, especially in areas where digital literacy was lower. The scalability of this model, while promising, depends on local capacity, ongoing teacher engagement, and the flexibility of curriculum frameworks to accommodate digital tools. Moreover, the persistence of behavioral change will require repetition, reinforcement, and policy-level support, as highlighted in other studies on long-term educational behavior change [24].

Because the pre- and post-intervention surveys were conducted as repeated cross-sectional samples rather than matched observations, the observed differences should be interpreted as population-level shifts in awareness, attitudes, and behaviors, rather than individual behavioral trajectories. This design choice reflects practical constraints in school-based educational settings but should be acknowledged when considering causal inferences at the individual level.

In sum, the integration of ArcGIS StoryMap and related digital tools into a school-wide SUP reduction strategy offers a replicable model for blended environmental education. By combining cognitive learning with spatial interaction and behavioral reinforcement, this study demonstrates how geospatial technologies can effectively bridge the gap between knowledge and action. The findings underscore the relevance of such approaches for engaging Generation Z learners, who are simultaneously navigating the dual challenges of environmental degradation and digital transformation. Such approaches offer a practical pathway for aligning environmental education with digital transformation agendas while grounding behavioral change in place-based learning.

5. Conclusion

Plastic waste, particularly SUPs, poses a significant environmental challenge that demand context-specific and age-appropriate solutions. This study demonstrated the potential of combining spatially enabled tools, such as ArcGIS StoryMap, with a school-based waste-sorting model to raise awareness and catalyze behavior change among students. By visualizing student awareness and behavioral patterns through interactive surveys, dashboards, and storytelling, the intervention fostered greater engagement and pro-environmental intentions Plastic waste, particularly single-use plastics (SUPs), poses a significant environmental challenge that demands context-specific and age-appropriate educational solutions. This study demonstrated the potential of combining spatially enabled tools, such as ArcGIS StoryMap, with a school-based waste-sorting model to raise awareness and support behavior change among students. By visualizing student awareness and behavioral patterns through interactive surveys, dashboards, and spatial storytelling, the intervention fostered engagement and pro-environmental intentions within the school community.

From a methodological perspective, the study employed a repeated cross-sectional design combined with non-parametric pre–post tests and post-intervention correlation analysis to examine changes in students' knowledge, attitudes, perceived behavioral control, and behaviors related to SUP reduction. The results indicate statistically significant improvements in key awareness indicators and modest behavioral shifts, particularly in usage frequency and disposal-related practices. Correlation patterns further suggest that attitudinal factors were more strongly associated with pro-environmental behaviors than knowledge alone, consistent with the Theory of Planned Behavior. The integration of GIS-based tools enabled students to link abstract environmental concepts with everyday practices and local contexts through participatory features such as waste hotspot mapping and locally grounded solution proposals. These findings highlight the added value of combining geospatial technologies with place-based learning approaches in environmental and sustainability education. Although the observed behavioral changes were modest, they underscore the role of digital geospatial tools as effective complements to physical infrastructure and institutional support. Future research should focus on enhancing StoryMap interactivity, extending the model to additional schools, and exploring real-time data integration to strengthen long-term behavioral reinforcement. Overall, this study provides a scalable and replicable framework for embedding GIS-based tools into school curricula to support sustainability-oriented learning and digital transformation initiatives.

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