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# Proactive Technology-Mediated Informal Learning in Community Environmental Education: A STOPS Analysis of Housewives' Engagement in Urban Zero Waste Practices

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## ABSTRACT

Urban waste management remains a persistent environmental challenge, with household practices playing a pivotal role in shaping sustainability outcomes. In urban communities, housewives occupy a strategic position in household waste reduction; however, the learning processes through which environmental engagement emerges in everyday life remain insufficiently theorized. This study examines how situational perceptions influence household environmental engagement in zero-waste practices through proactive informal environmental learning (PIEL), drawing on the Situational Theory of Problem Solving (STOPS) and an infrastructure-oriented view of technology-mediated learning. Using a quantitative, cross-sectional survey of 1,668 urban housewives engaged in community-based zero-waste activities, the study applies regression-based mediation and moderated mediation analyses with Hayes' PROCESS macro. The findings indicate that situational perceptions shape environmental engagement primarily through a serial mechanism involving situational motivation and proactive informal learning, rather than through direct effects alone. Moreover, digital technology use strengthens the translation of situational perceptions into informal learning but does not moderate the subsequent relationship between learning and engagement. These results position informal, practice-based learning as a central mechanism in community environmental education and conceptualize digital technology as an enabling infrastructure for learning initiation, rather than a direct driver of behavioral outcomes. Overall, the study advances a context-sensitive, learner-centered framework for understanding environmental engagement in urban community settings.

**Keywords**: Technology-Mediated Learning; Community Environmental Education; Informal Learning; Situational Theory of Problem Solving; Zero Waste.

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## INTRODUCTION

Urban domestic waste continues to pose a significant environmental challenge, as rapid urbanization and increasing household consumption frequently outpace the capacity of waste management infrastructure and the rate of behavioral change, particularly in Asian and African cities (Cheng et al. 2022; Z. Zhang et al. 2024). This challenge is especially pronounced in the Greater Jakarta metropolitan area (Jakarta, Bogor, Depok, Tangerang, and Bekasi), a densely populated urban agglomeration characterized by high household waste generation, complex service infrastructures, and widespread penetration of digital technologies that shape everyday environmental practices. Within this context, housewives occupy a strategic position in facilitating household-level waste reduction. They are often primarily responsible for sustainability-related domestic labor and strongly influence everyday practices such as food management, waste sorting, and participation in community initiatives (Antriyandarti et al. 2023; Lindsay et al. 2024). Empirical evidence consistently shows that women are more likely than men to engage in waste separation and adopt zero-waste routines, positioning them as key agents of environmental change within urban households (Tang et al. 2022; Taye, Assefa, and Simane 2023). As a result, community environmental education increasingly emphasizes housewives' environmental engagement as a critical learning outcome, manifested in the development of civic attitudes, sustainability skills, and pro-environmental behaviors embedded in daily routines (N. Ardoin, Bowers, and Gaillard 2022; Ballard, Lindell, and Jadallah 2024).

Environmental engagement in community contexts is widely recognized as a multidimensional construct that encompasses cognitive understanding, emotional commitment, and behavioral responses to environmental issues (N. M. Ardoin and Bowers 2020; Hajj-Hassan, Chaker, and Cederqvist 2024; Lianfeng et al. 2023). Such engagement is often cultivated through informal environmental learning— learning that is typically self-directed, experiential, and situated within everyday household and community practices rather than structured in formal education settings (Ardoin & Heimlich, 2021; Ruiz-Mallén et al., 2022). Through repeated actions such as waste sorting, food management, and resource conservation, individuals gradually acquire environmental knowledge, habits, and competencies that reinforce long-term pro-environmental behavior (Baptista, Pinho, and Alves 2025; Kalla et al. 2022). However, much of the environmental education literature has focused on formal settings and designed interventions, leaving informal and proactive learning processes within domestic environments underexplored (N. M. Ardoin and Heimlich 2021; Lianfeng et al. 2023).

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To address this gap, the Situational Theory of Problem Solving (STOPS) offers a useful framework for understanding how individuals engage in proactive learning in response to complex social and environmental issues. STOPS suggests that *problem recognition*, *involvement recognition*, and *constraint recognition* shape an individual's *situational motivation*, which subsequently drives proactive communicative behaviors such as information seeking, feedback seeking, and help seeking (Akbulut 2023; Bhalla 2022; C. Li et al. 2025). Empirical studies have shown that stronger situational motivation leads to increased efforts to acquire knowledge and mobilize resources to address perceived problems (Dam and Basaran 2025; C. Li et al. 2025). While STOPS has been widely applied in communication and public relations, its application in the field of environmental education—especially within informal, household, and community-based learning contexts—remains limited (Bhalla 2022).

In this regard, digital technologies are increasingly mediating proactive learning in urban environments by serving as channels of information, social learning spaces, and infrastructures for informal education. Urban residents frequently turn to search engines, social media platforms, and mobile applications to access environmental information, share experiences, and engage in collective problemsolving and meaning-making beyond immediate geographic boundaries (Lin and Ardoin 2023; Villamil and King 2024). Although prior studies in environmental education often frame digital technology as an external tool or intervention, such perspectives may overlook its deeper function as a pervasive, embedded infrastructure that subtly influences what, how, and with whom individuals learn (Burbules, Fan, and Repp 2020; Goodyear 2021). Informal environmental learning increasingly occurs through digital networks, which support daily problem-solving around issues such as waste reduction and sustainable practices (Agboola and Tunay 2023).

Despite increasing research on environmental engagement and digital technology, several important gaps remain. First, few studies have examined how situational perceptions—such as problem recognition, perceived involvement, and perceived constraints—directly influence informal learning processes within the household, even though literature on home learning and disaster preparedness indicates their relevance (Daucourt et al. 2021; Ni et al. 2025). Second, although STOPS has been widely applied in domains such as health and risk communication, its integration into community-based environmental education is still underdeveloped (Akbulut 2023; Dam and Basaran 2025). Third, while the role of technology in facilitating learning has been increasingly acknowledged, its function as a moderator that shapes how situational learning emerges remains under-theorized (C. Li et al. 2025; Riofrío-Calderón and Ramírez-Montoya 2022).

Despite growing research on environmental engagement and digital learning, three gaps remain. First, limited attention has been paid to how situational perceptions drive informal environmental learning within domestic contexts. Second, applications of STOPS in community environmental education remain scarce, particularly in explaining learning-driven engagement rather than communicative outcomes alone. Third, the role of digital technology has often been treated as an external tool rather than as a conditional infrastructure shaping learning processes. Addressing these gaps is critical for developing more contextsensitive environmental education frameworks.

This study seeks to address these gaps by integrating the STOPS framework into an analysis of proactive informal environmental learning in technology-mediated community settings. Specifically, it aims to elucidate how situational perceptions influence environmental engagement through informal learning among housewives in urban contexts. The study investigates the effects of problem recognition, involvement recognition, situational motivation, and perceived constraints on proactive informal environmental learning. It further examines whether such informal learning mediates the relationship between situational perceptions and household engagement in zero-waste practices. Rather than assuming that digital tools universally enhance learning, this study explores the extent to which technology moderates the relationship between situational perceptions and informal learning behaviors. Based on these objectives, three hypotheses are proposed: H1 posits significant associations between situational factors and proactive informal learning; H2 suggests that proactive informal learning mediates the link between situational perceptions and environmental engagement; and H3 proposes that technology moderates this indirect relationship by amplifying learning outcomes. A complete picture of the path diagram of all the variables tested in this study can be seen in the following image.

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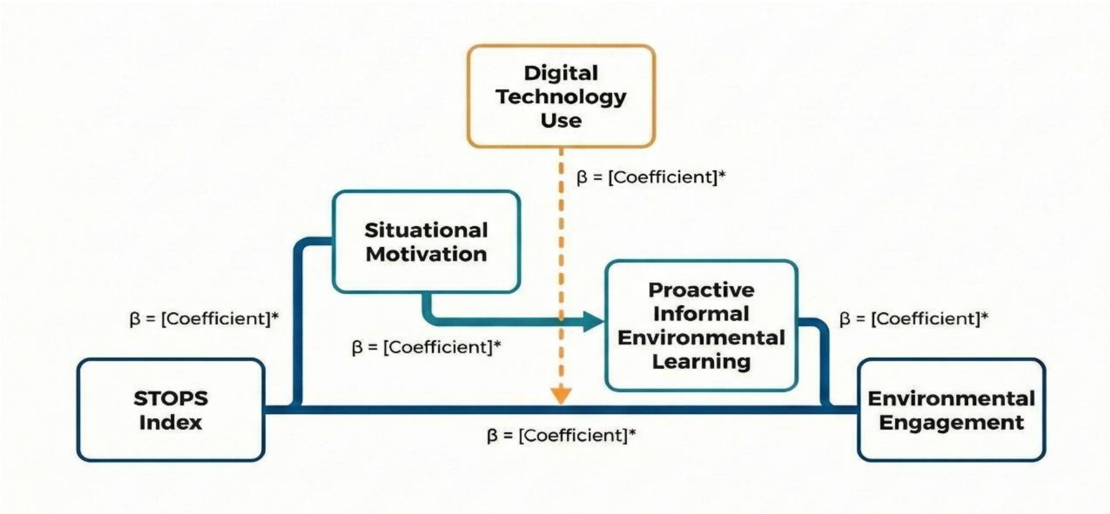


**Figure 1 Moderated Serial Mediation Path Diagram**

## RESEARCH METHODS

This study employed a quantitative cross-sectional survey with an explanatory orientation to test theoretically grounded associations among situational perceptions (STOPS), proactive informal environmental learning (PIEL), and household environmental engagement, including zero-waste practices. A cross-sectional design is appropriate for capturing population-level variation in perceptions and behaviors at a single time point and has been widely adopted to examine psychological and learning-related mechanisms in environmental and community contexts (Eshete, Desalegn, and Tigu 2023; C. Li et al. 2025; Miner et al. 2020). The explanatory approach enabled the empirical testing of hypothesized pathways—particularly mediation and moderated mediation—while maintaining interpretive caution regarding temporal ordering and causal inference (N. M. Ardoin, Bowers, and Gaillard 2022; Deltomme, Gorissen, and Weijters 2023).

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***1. Data Source and Participants***

Data were collected through a large-scale survey conducted in the Greater Jakarta metropolitan area of Indonesia, encompassing Jakarta, Bogor, Depok, Tangerang, and Bekasi. This region was selected because it represents a highly urbanized and densely populated metropolitan context characterized by substantial household waste generation, established community-based environmental initiatives, and widespread access to digital technologies relevant to informal learning processes.

The survey targeted urban housewives who were involved in community environmental activities and/or routine household waste management practices. This population was selected because housewives commonly perform sustainability-related domestic labor and function as key household decision-makers in waste-related practices, making them particularly relevant for examining proactive informal environmental learning embedded in everyday routines (Antriyandarti et al. 2023; Lindsay et al. 2024). Household-based surveys are also widely used in environmental behavior research, including studies on knowledge–attitudes–practices (KAP) and participation in waste management programs (Almulhim 2022; Eshete, Desalegn, and Tigu 2023; Miner et al. 2020). The final analytical sample consisted of 1,668 urban housewives, providing sufficient statistical power for estimating mediation and moderated mediation effects using regression-based conditional process models.

***2. Measures and Variables***

All constructs were measured using multi-item instruments tailored to the household waste context. Unless otherwise specified, items were rated on a 4-point Likert scale to encourage response differentiation while minimizing central tendency bias.

*Independent Variables: Situational Perceptions (STOPS)*

Situational perceptions were operationalized according to four core STOPS constructs: problem recognition, involvement recognition, constraint recognition, and situational motivation. These constructs capture, respectively, perceived seriousness of the household waste problem,

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perceived personal relevance, perceived internal/external barriers to action, and the motivation to solve waste-related problems. STOPS operationalizations using Likert-type indicators have shown robust psychometric performance across public-issue domains and have been used to predict information behaviors and problem-solving actions (Dam and Basaran 2025; C. Li et al. 2025; Liu et al. 2023; X. Zhang et al. 2023). Items were contextualized to household waste and zero-waste practices while preserving the conceptual meaning of each STOPS dimension (Akbulut 2023; C. Li et al. 2025).

*Mediator: Proactive Informal Environmental Learning (PIEL)*

PIEL was conceptualized as proactive, self-directed learning embedded in everyday life and social interaction. The measure captured proactive learning behaviors aligned with the informal learning literature (N. M. Ardoin and Heimlich 2021) and with STOPS' emphasis on communicative action in problem solving (C. Li et al. 2025). PIEL comprised four dimensions: (1) environmental feedback seeking, (2) ecological help seeking, (3) ecological information seeking, and (4) frequency of help/information seeking. This operationalization is consistent with validated approaches to proactive social informal learning (Crans et al. 2023) and with evidence that help-seeking and related strategies function as mechanisms linking prior perceptions/knowledge to engagement and learning outcomes (Dong, Jong, and King 2020).

Response options ranged from 1 (“never”) to 4 (“very often”).

*Moderator: Technology Use*

Technology use was modeled as a moderator of the relationship between situational perceptions and PIEL, reflecting the view that technology can condition whether situational motivation is converted into active learning. Technology was measured via indicators capturing (a) use of digital information channels (e.g., social media and mobile applications) and (b) information acquisition and sharing behaviors. This approach is aligned with perspectives that treat technology not merely as a discrete intervention but as an embedded learning infrastructure shaping access, participation, and informal learning processes (Burbules, Fan, and Repp 2020; Goodyear 2021).

The moderator framing is also consistent with evidence that characteristics of the digital environment can intensify the effects of learning drivers on engagement and outcomes in technology-mediated settings (Y. Li, Chen, and Deng 2024) and with broader mappings of online learning mediation mechanisms (Riofrío-Calderón and Ramírez-Montoya 2022).

*Dependent Variables: Household Environmental Engagement and Zero-Waste Practices*

Two outcome domains were examined:

1. Household environmental engagement, conceptualized as a multidimensional construct including cognitive, emotional, and behavioral engagement in environmental issues (N. M. Ardoin, Bowers, and Gaillard 2022; Ballard, Lindell, and Jadallah 2024).
2. Household zero-waste practices, measured via specific waste-related behaviors such as waste sorting, waste reduction actions, and participation in community-based waste initiatives. The operationalization follows household waste management research using behavior frequency and participation indicators to capture practical sustainability actions (Almulhim 2022; Eshete, Desalegn, and Tigu 2023; Miner et al. 2020).

This dual-outcome strategy allows the study to distinguish learning-related engagement from specific behavioral enactments of waste reduction.

*Control Variables*

To reduce confounding, analyses controlled for demographic and contextual factors that are repeatedly shown to influence environmental practices and access to learning opportunities: age, education level, and availability of local waste services (Eshete, Desalegn, and Tigu 2023; Fadhullah et al. 2022). Where relevant, these controls were entered in all models before estimating focal predictors and interaction terms.

*Operationalization of Variables*

**Table 1 Operationalization of Research Variables**

| Variable / Construct | Indicators / Dimensions | Measurement Scale | Source / Theoretical Basis | Role in Analysis |
| --- | --- | --- | --- | --- |

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| Variable / Construct | Indicators / Dimensions | Measurement Scale | Source / Theoretical Basis | Role in Analysis |
|---|---|---|---|---|
| Situational Perceptions (STOPS) | Problem recognition (perceived seriousness of household waste problems); Involvement recognition (perceived personal relevance to household and environmental contexts); Constraint recognition (perceived internal and external barriers to acting or learning); Situational motivation (motivation to solve waste-related problems) | Likert scale (1 = strongly disagree to 4 = strongly agree) | Situational Theory of Problem Solving (Kim and Grunig 2011); empirical STOPS applications in public issues and community (Akbulut 2023; Bhalla 2022; Dam and Basaran 2025; C. Li et al. 2025) | Independent variables (X) |
| Proactive Informal Environmental Learning (PIEL) | Environmental feedback seeking; Ecological help seeking; Ecological information seeking; Frequency of help and information seeking | Likert scale (1 = never to 4 = very often) | Informal and proactive learning theory (N. M. Ardoin and Heimlich 2021); Proactive Social Informal Learning frameworks (Crans et al. 2023); learning-asmechanism models (Dong, Jong, and King 2020) | Mediating variable (M) |
| Technology Use | Use of digital information | Dichotomous | | |

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| | | | | |
|---|---|---|---|---|
| | channels (e.g., social media, mobile applications); Information acquisition and sharing behaviors related to environmental issues | and Likert scale | Technology-mediated and infrastructure-based learning perspectives (Burbules, Fan, and Repp 2020; Goodyear 2021); moderation evidence in digital learning environments (Y. Li, Chen, and Deng 2024; Riofrío-Calderón and Ramírez-Montoya 2022). | Moderating variable (W) |
| Household Environmental Engagement | Cognitive engagement (awareness and understanding of environmental issues); Emotional engagement (concern and commitment); Behavioral engagement | Likert scale | Environmental engagement and education outcome frameworks (N. M. Ardoin, Bowers, and Gaillard 2022; Ballard, Lindell, and Jadallah 2024; Lianfeng et al. 2023). | Dependent variable ($Y_1$) |
| Variable / Construct | Indicators / Dimensions | Measurement Scale | Source / Theoretical Basis | Role in Analysis |
| | (participation in proenvironmental actions) | | | |
| Household Zero-Waste Practices | Waste sorting; Waste reduction behaviors; Participation in zerowaste or communitybased waste initiatives | Categorical and Likert scale | Household waste management and KAP studies (Almulhim 2022; Eshete, Desalegn, and Tigu 2023; Fadhullah et al. 2022; Miner et al. 2020) | Dependent variable ($Y_2$) |

| | | | | |
|---|---|---|---|---|
| Control Variables | Age; Education level; Availability of local waste services | Categorical | Environmental behavior and household waste literature identifying demographic and contextual influences (Eshete, Desalegn, and Tigu 2023; Fadhullah et al. 2022; Miner et al. 2020). | Control variables |

### *3. Hypotheses and Model Specification*

Guided by the proposed conceptual framework, this study tested three hypotheses that mirror the research objectives stated in the Introduction. H1 posits significant associations between situational perceptions—problem recognition, involvement recognition, situational motivation, and perceived constraints (constraint recognition)—and proactive informal environmental learning (PIEL) (Akbulut 2023; Bhalla 2022; C. Li et al. 2025). H2 proposes that PIEL mediates the relationship between situational perceptions and household environmental engagement in zerowaste practices, reflecting a learning-driven pathway from situational appraisal to engagement and behavioral enactment (N. M. Ardoin and Heimlich 2021; Crans et al. 2023; Dong, Jong, and King 2020). H3 proposes that technology moderates this indirect relationship by strengthening the effect of situational perceptions on PIEL, thereby amplifying learning-linked engagement outcomes in household zero-waste practices (Burbules, Fan, and Repp 2020; Goodyear 2021; C. Li et al. 2025; Y. Li, Chen, and Deng 2024).

To avoid construct ambiguity, the study uses the following consistent terminology across sections: (i) situational perceptions refer to the four STOPS constructs listed above; (ii) PIEL denotes proactive, self-directed informal environmental learning behaviors; (iii) technology denotes technology use as an embedded learning infrastructure; and (iv) the primary outcome is household environmental engagement in zero-waste practices, encompassing cognitive, emotional, and behavioral engagement as expressed through household waste-related actions.

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### *4. Data Analysis*

Data analysis was designed to match the study's theoretical logic—namely, that situational perceptions shape learning-oriented behaviors (PIEL), which in turn explain variation in household environmental engagement in zero-waste practices, and that technology conditions the strength of this learning pathway. Accordingly, a staged analytical strategy was employed to (a) confirm measurement quality, (b) construct composite variables, and (c) test the hypothesized mediation and moderated mediation pathways using regression-based conditional process modeling.

1. Reliability testing**.** Internal consistency of multi-item measures was assessed using Cronbach's alpha. Coefficients at or above conventional thresholds were treated as acceptable for researchscale reliability (Deltomme, Gorissen, and Weijters 2023).
2. Composite score construction**.** For each construct, composite scores were computed by averaging items within the scale to represent each latent concept with a single index, consistent with common practice in applied environmental behavior and learning research when internal consistency is adequate (Deltomme, Gorissen, and Weijters 2023).
3. Mediation and moderated mediation modeling**.** Hypotheses were tested using Hayes' PROCESS Macro within an ordinary least squares regression framework. Mediation (H2) was evaluated by estimating indirect effects of situational perceptions on household environmental engagement in zero-waste practices through PIEL. Moderated mediation (H3) was assessed by incorporating technology as a moderator of the path from situational perceptions to PIEL, thereby testing conditional indirect effects across levels of technology use (C. Li et al. 2025; Y. Li, Chen, and Deng 2024).
4. Bootstrapped inference**.** The significance of indirect and conditional indirect effects was determined using bias-corrected bootstrapping with 5,000 resamples and 95% confidence intervals, which is recommended for robust inference in mediation and conditional process analysis (Deltomme, Gorissen, and Weijters 2023).

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Overall, this analytic design ensures coherence between the study's conceptual framework and its empirical tests: the measurement strategy operationalizes STOPS-based situational perceptions, PIEL captures learning-driven mechanisms consistent with informal learning theory, and the conditional process approach directly evaluates whether technology strengthens the translation of situational perceptions into proactive informal learning and, ultimately, household environmental engagement in zero-waste practices. While the cross-sectional design limits causal claims, the combination of theoretically grounded constructs and bootstrapped conditional indirect-effect testing provides a rigorous basis for evaluating the plausibility and strength of the hypothesized learning pathway in an urban household context (Eshete, Desalegn, and Tigu 2023; C. Li et al. 2025; Miner et al. 2020).

## RESULTS AND DISCUSSION

### Results

#### *1. Descriptive Statistics and Preliminary Analysis*

Analyses were conducted on data from 1,668 urban housewives who participated in community-based environmental activities and routine household waste management practices. Preliminary reliability testing indicated strong internal consistency for the Proactive Informal Environmental Learning (PIEL) scale (Cronbach's $\alpha = .93$, four items), supporting the construction of a composite PIEL index for subsequent analyses. All composite variables were computed prior to hypothesis testing, and focal predictors were mean-centered to reduce multicollinearity when estimating interaction terms.

As shown in Table 2, the study variables exhibited adequate variability and statistically meaningful intercorrelations, indicating suitability for regression-based mediation and moderated mediation analyses. Zero-order correlations revealed strong positive associations among situational perceptions (STOPS), situational motivation, PIEL, and environmental engagement, providing preliminary support for the hypothesized learning-mediated pathways. Subsequent

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inferential analyses employed bias-corrected bootstrapping with 5,000 resamples and 95% confidence intervals, consistent with best practices for indirect effect estimation.

**Table 2**

**Descriptive Statistics and Zero-Order Correlations Among Situational Perceptions, Proactive Informal Environmental Learning, Environmental Engagement, And Digital Technology Use (N = 1,668)**

| Variable | Mean | SD | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1. STOPS Index (STOPS_c) | 0.00 | 2.23 | — | | | | |
| 2. Situational Motivation (SM_c) | 0.00 | 1.10 | .76*** | — | | | |
| 3. Proactive Informal Environmental Learning (PIEL_c) | 0.00 | 1.00 | .74*** | .72*** | — | | |
| 4. Environmental Engagement (EE) | 2.50 | 0.75 | .71*** | .63*** | .70*** | — | |
| 5. Digital Technology Use (DTU) | 0.60 | 0.49 | .32*** | .29*** | .35*** | .30*** | — |

**Notes:**

Means and standard deviations are reported for all study variables. Correlations are Pearson's r. STOPS = situational perceptions (mean-centered composite index); SM = situational motivation; PIEL = proactive informal environmental learning; EE = household environmental engagement; DTU = digital technology use (coded 0 = low use, 1 = high use). Centered variables reflect meancentering prior to interaction and conditional process analyses.

***p < .001*

***2. Serial Mediation of Situational Perceptions on Environmental Engagement (PROCESS Model 6)***

To test H1 and H2, a serial mediation model (PROCESS Model 6) was estimated in which situational perceptions (STOPS_c) predicted situational motivation (SM_c), which in turn predicted proactive informal environmental learning (PIEL_c), culminating in household environmental engagement (EE). This model reflects the theorized STOPS-based sequence whereby situational appraisal activates motivation, stimulates learning-oriented behaviors, and ultimately translates into engagement.

As shown in Table 3, results supported the hypothesized sequential mechanism. First, STOPS_c exerted a strong positive effect on situational motivation ($b = 0.3808$, $p < .001$), indicating that stronger recognition of household waste problems, greater perceived involvement, and fewer perceived constraints were associated with higher motivation to address the issue. Second, both STOPS_c ($b = 0.0971$, $p < .001$) and situational motivation ($b = 0.5151$, $p < .001$) significantly predicted PIEL_c, with situational motivation emerging as the stronger predictor. This pattern suggests that situational perceptions foster proactive informal learning both directly and indirectly through heightened motivation.

In the final outcome equation, PIEL_c emerged as the strongest predictor of environmental engagement ($b = 0.5167$, $p < .001$), underscoring the central role of informal learning processes in shaping engagement outcomes. STOPS_c remained a significant direct predictor of engagement ($b = 0.1183$, $p < .001$), while situational motivation also contributed positively, albeit more modestly ($b = 0.0766$, $p = .012$). Together, these findings indicate that engagement is jointly shaped by situational appraisal and learning-based mechanisms.

Bootstrapped indirect effect estimates further corroborated the serial mediation model. As summarized in Table 3, the total indirect effect of STOPS_c on environmental engagement was statistically significant (effect = 0.1807, 95% CI [0.1587, 0.2047]). Decomposition of indirect effects revealed three significant pathways: through situational motivation alone, through PIEL alone, and through the full serial pathway (STOPS_c → SM_c → PIEL_c → EE). Notably, the serial indirect effect was the largest (effect = 0.1014, 95% CI [0.0874, 0.1162]), providing strong empirical support for a motivational–learning mechanism consistent with STOPS.

When demographic and contextual covariates were included, the overall pattern of results remained stable. Local waste service availability was positively associated with both situational motivation and PIEL, suggesting that infrastructural support facilitates motivational and learning processes. Education level showed a small positive association with environmental engagement, whereas age did not exhibit statistically meaningful effects in the focal outcome equation. Importantly, the hypothesized mediation pathways were robust to covariate adjustment, indicating that the observed effects were not attributable to these background factors.

**Table 3**

**Serial Mediation Effects of Situational Perceptions (STOPS) On Household Environmental Engagement Through Situational Motivation and Proactive Informal Environmental Learning (PROCESS Model 6).**

| Path | Effect | Boot SE | 95% Boot CI |
|---|---|---|---|
| STOPS → SM | 0.381*** | — | — |
| STOPS → PIEL | 0.097*** | — | — |
| SM → PIEL | 0.515*** | — | — |
| PIEL → EE | 0.517*** | — | — |
| **Direct Effect (STOPS → EE)** | 0.118*** | 0.014 | [0.092, 0.145] |
| **Indirect Effects** | | | |
| STOPS → SM → EE | 0.029 | 0.012 | [0.006, 0.055] |
| STOPS → PIEL → EE | 0.050 | 0.007 | [0.038, 0.064] |
| STOPS → SM → PIEL → EE | 0.101 | 0.007 | [0.087, 0.116] |
| **Total Indirect Effect** | 0.181 | 0.012 | [0.159, 0.205] |

**Notes:**

Notes. Unstandardized regression coefficients are reported. STOPS = situational perceptions (mean-centered composite index); SM = situational motivation; PIEL = proactive informal

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environmental learning; EE = household environmental engagement. Indirect effects were estimated using bias-corrected bootstrapping with 5,000 resamples. Confidence intervals that do not include zero indicate statistically significant indirect effects. All models control for age, education level, and local waste service availability.

**$p < .001$

When demographic and contextual covariates were included, the overall pattern of results remained stable. Local waste service availability was positively associated with both situational motivation and PIEL, suggesting that infrastructural support facilitates motivational and learning processes. Education level showed a small positive association with environmental engagement, whereas age did not exhibit statistically meaningful effects in the focal outcome equation. Importantly, the hypothesized mediation pathways were robust to covariate adjustment, indicating that the observed effects were not attributable to these background factors.

***3. Moderation of the Learning-to-Engagement Link (PROCESS Model 14)***

To examine whether digital technology use (DTU) moderates the relationship between PIEL and environmental engagement, a moderated mediation model (PROCESS Model 14) was estimated, with moderation specified on the PIEL_c → EE path.

Results indicated that STOPS_c remained a significant predictor of PIEL_c ($b = 0.2932$, $p < .001$), and PIEL_c continued to strongly predict environmental engagement ($b = 0.5564$, $p < .001$). However, the interaction between PIEL_c and DTU was not statistically significant ($b = -0.0083$, $p = .839$), and the inclusion of the interaction term did not meaningfully increase explained variance. The index of moderated mediation was likewise non-significant, as its bootstrap confidence interval included zero. These findings indicate that while proactive informal learning is robustly associated with engagement, the strength of this association does not differ systematically by level of digital technology use.

***4. Moderated Mediation via the Situational-to-Learning Pathway (PROCESS Model 58)***

Given the theoretical framing of technology as an enabling infrastructure, a more comprehensive moderated mediation model (PROCESS Model 58) was estimated to test whether DTU moderates the translation of situational perceptions into proactive informal environmental learning. In this model, DTU was specified as a moderator of both the STOPS_c → PIEL_c and PIEL_c → EE paths.

As shown in Table 4, results provided clear evidence of moderation in the situational-tolearning pathway. In the mediator equation, STOPS_c remained a significant predictor of PIEL_c ($b = 0.2173$, $p < .001$), and the interaction between STOPS_c and DTU was statistically significant ($b = 0.1253$, $p < .001$), accompanied by a meaningful increase in explained variance ($\Delta R^2 = 0.0179$, $p < .001$). Conditional effects analysis indicated that the effect of situational perceptions on proactive informal environmental learning was substantially stronger among participants with higher digital technology use.

In contrast, consistent with Model 14, the interaction between PIEL_c and DTU in the outcome equation was not significant. Thus, digital technology use selectively strengthens the emergence of proactive informal environmental learning from situational perceptions but does not alter the impact of learning on engagement outcomes.

Bootstrapped conditional indirect effects confirmed this pattern. As reported in Table 4, the indirect effect of STOPS_c on environmental engagement via PIEL was significant at both levels of DTU but was notably larger under high technology use. The index of moderated mediation was positive and statistically significant, indicating that digital technology use meaningfully amplifies the magnitude of the indirect effect through proactive informal learning.

**Table 4**

**Moderated Mediation Effects of Digital Technology Use (DTU) On the Indirect Association Between Situational Perceptions (STOPS) And Household Environmental Engagement Via Proactive Informal Environmental Learning**

| Model | Moderated Path | Index of Moderated Mediation | Boot SE | 95% Boot CI |
|---|---|---|---|---|
| Model 14 | PIEL × DTU → EE | −0.002 | 0.011 | [−0.023, 0.019] |
| Model 58 | STOPS × DTU → PIEL | **0.067*** | 0.013 | [0.041, 0.091] |

**Notes:**

Results are based on regression-based conditional process analyses using Hayes' PROCESS Macro. Model 14 tests moderation on the learning-to-engagement path (PIEL → EE), whereas Model 58 tests moderation on both the situational-to-learning path (STOPS → PIEL) and the learning-to-engagement path. DTU = digital technology use (coded 0 = low use, 1 = high use). Indices of moderated mediation were estimated using bias-corrected bootstrapping with 5,000 resamples. Confidence intervals that do not include zero indicate statistically significant moderated mediation effects. All models include controls for age, education level, and local waste service availability.

**$p < .001$

***5. Summary of Hypothesis Testing***

Across all models, the results converge on a coherent and theoretically consistent pattern. The findings provide strong support for H1 and H2, demonstrating that situational perceptions are associated with household environmental engagement both directly and indirectly through situational motivation and proactive informal environmental learning. The moderated mediation analyses partially support H3, revealing that digital technology use amplifies the situational-tolearning pathway but does not moderate the learning-to-engagement relationship. Collectively, these results suggest that technology functions primarily as an enabling infrastructure that strengthens situationally driven informal learning processes, rather than reshaping how learning translates into engagement outcomes.

**Discussion**

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### *1. Summary of Key Findings*

This study examined how situational perceptions, as conceptualized by the Situational Theory of Problem Solving (STOPS), are translated into household environmental engagement in zero-waste practices through proactive informal environmental learning (PIEL), and how digital technology use conditions this process in a community environmental education context. Overall, the findings provide strong empirical support for a learning-centered explanation of engagement, in which situational appraisal initiates motivational and learning processes that culminate in environmentally engaged cognition and behavior.

Results from the serial mediation analysis (PROCESS Model 6) demonstrate that situational perceptions exert both direct effects on environmental engagement and indirect effects through situational motivation and PIEL. Importantly, the serial pathway from situational motivation to proactive informal learning emerged as the strongest indirect mechanism, indicating that engagement among urban housewives is not merely an attitudinal response to environmental problems but is deeply rooted in everyday learning processes embedded in household problem solving. This finding aligns with prior work emphasizing that sustained environmental engagement is more likely to emerge from repeated, practice-based learning than from isolated informational exposure (N. M. Ardoin and Heimlich 2021; Ballard, Lindell, and Jadallah 2024).

The moderated mediation analyses further clarify the role of technology. While digital technology use significantly strengthened the situational perceptions → proactive informal learning pathway, it did not moderate the learning → engagement relationship. This pattern suggests that technology primarily functions as an upstream enabler of learning initiation, rather than as a determinant of how learning is translated into engagement outcomes. Together, these results point to a selective and theoretically meaningful role of technology within the STOPSbased learning mechanism.

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***2. Theoretical Implications***

This study contributes to the literature in several important ways. First, by empirically validating a serial mediation model linking STOPS to environmental engagement through motivation and informal learning, the findings extend STOPS beyond its traditional applications in communication, public relations, and risk contexts (Akbulut 2023; Bhalla 2022; C. Li et al. 2025) into the domain of community-based environmental education. Rather than treating engagement as a direct outcome of problem recognition or involvement, the results demonstrate that learning-oriented processes are central explanatory mechanisms through which situational perceptions shape engagement.

Second, the strong mediating role of proactive informal environmental learning advances theoretical discussions on environmental engagement by foregrounding learning as an active, selfdirected, and practice-based process. Consistent with informal learning theory, this form of learning is embedded in routine household activities—such as waste sorting, reuse, and food management—rather than formal instructional settings (N. M. Ardoin and Heimlich 2021; Crans et al. 2023). By positioning PIEL as a mediator rather than a peripheral outcome, this study responds to calls in environmental education research to better theorize how learning-in-action connects situational awareness to sustained engagement (N. M. Ardoin, Bowers, and Gaillard 2022).

Third, the moderated mediation findings refine conceptualizations of technology's role in environmental learning. The fact that technology strengthens the situational-to-learning pathway but does not alter the learning-to-engagement link supports an infrastructural view of technology, in which digital tools facilitate access to information, social exchange, and learning opportunities without dictating behavioral outcomes (Burbules, Fan, and Repp 2020; Goodyear 2021). This challenges technologically deterministic assumptions and aligns with recent work emphasizing that technology shapes *conditions of learning* rather than *engagement per se* (Lin and Ardoin 2023; Riofrío-Calderón and Ramírez-Montoya 2022).

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Collectively, these findings suggest that the explanatory power of STOPS in environmental education is strongest when situationally meaningful problems intersect with everyday learning opportunities, highlighting the importance of contextually grounded learning processes over abstract environmental messaging.

***3. Implications for Community Environmental Education and Practice***

Beyond theory, this study offers several implications for community environmental education and grassroots sustainability initiatives. The findings indicate that environmental engagement among urban housewives emerges primarily through situationally driven informal learning, rather than through formal instruction or externally imposed programs. Accordingly, community education efforts may be more effective when they focus on enhancing problem recognition, personal relevance, and perceived efficacy, thereby fostering situational motivation that naturally stimulates proactive learning behaviors.

The central role of PIEL suggests that everyday household practices function as critical learning spaces. Programs that encourage peer exchange, experiential sharing, and collective reflection on routine practices may therefore be more impactful than one-off workshops or information campaigns. In this regard, housewives should be viewed not only as implementers of environmental behavior but also as active learners and knowledge brokers within household and neighborhood contexts (Antriyandarti et al. 2023; Lindsay et al. 2024).

The nuanced role of digital technology further implies that community education initiatives need not be technologically intensive to be effective. While digital platforms can support learning initiation by expanding access to information and social networks, sustained engagement appears to depend more on embedded social relations and habitual practices. Practitioners are thus encouraged to position technology as a supportive scaffold, complementing—rather than replacing—face-to-face interaction, community norms, and daily routines in promoting zero-waste practices.

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### *4. Limitations and Directions for Future Research*

Several limitations should be acknowledged. First, the cross-sectional design limits causal inference regarding the temporal dynamics among situational perceptions, learning processes, and environmental engagement. Although the analytical models are theoretically grounded and statistically robust, future studies employing longitudinal or panel designs would allow for a more nuanced examination of how situational motivation and informal learning evolve over time and contribute to sustained engagement.

Second, digital technology use was measured at a relatively general level, focusing on access and overall use rather than specific platform affordances. Future research could employ more fine-grained measures to differentiate among digital environments—such as social media groups, messaging platforms, or community-based applications—and examine how these affordances differentially support informal environmental learning (Lin and Ardoin 2023).

Finally, the focus on urban housewives engaged in zero-waste practices enhances theoretical clarity but limits generalizability. Comparative studies across genders, rural–urban contexts, or alternative sustainability domains (e.g., energy conservation or water use) would help test the broader applicability of the STOPS–PIEL framework and further refine its relevance for diverse community environmental education settings.

## CONCLUSION

This study advances community environmental education research by demonstrating that environmental engagement is primarily shaped through a learning-centered mechanism, rather than by situational perceptions alone. Integrating the Situational Theory of Problem Solving (STOPS) with proactive informal environmental learning, the findings show that situational perceptions activate engagement indirectly through situational motivation and everyday learningoriented actions, including information seeking, feedback seeking, and help seeking. These processes operate as key pathways through which environmental awareness is translated into sustained household engagement in zero-waste practices.

The results further refine understanding of digital technology's role in community learning. Digital technology use strengthens the emergence of proactive informal learning from situational perceptions, yet does not directly amplify the effect of learning on engagement outcomes. This pattern positions technology as an enabling learning infrastructure that facilitates learning initiation, rather than as a driver of engagement per se. Overall, the study highlights that enduring environmental engagement among urban housewives is grounded in situationally meaningful problem-solving, social interaction, and informal learning embedded in everyday household practices. These insights underscore the importance of context-sensitive, learner-centered approaches in designing community-based environmental education and sustainability initiatives in urban settings.

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