Gamified Learning for Sustainable Eating: Exploring the Role of Prior Knowledge and Readiness to Change

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Abstract

Background: Dietary habits play a central role in the transition toward a more sustainable food system. However, many consumers lack an understanding of the principles of sustainable eating.

Objective: This study examined whether a gamified quiz could enhance knowledge about the environmental impact of food. Additionally, it explored the role of prior knowledge and readiness for change, based on the Transtheoretical Model (TTM), in the learning process.

Methods: A quasi-experimental, cross-sectional study with a pre-post design was conducted with 338 participants. Knowledge about sustainable eating was measured using a newly developed and piloted scale, and readiness for change was assessed using an adapted version of the TTM measures. The data were analyzed using t-tests, regression analyses, and variance analyses.

Results: The quiz led to a significant increase in knowledge, particularly among participants with low prior knowledge. Contrary to expectations, no significant differences in knowledge gain were observed based on readiness to change, as defined by the Transtheoretical Model.

Conclusion: Gamification has the potential to enhance knowledge about sustainable eating. Further research with more diverse samples and comprehensive measurement tools is needed to better understand the long-term effects on knowledge and to promote sustainable nutrition education in practice.

Keywords: CO_2, carbon footprint, sustainable nutrition, sustainable eating, prior knowledge, transtheoretical model, readiness to change, gamification, quiz

1 Introduction

Anthropogenic climate change is one of the greatest challenges of our time. Without a rapid, substantial, and sustained reduction in CO_2 and other greenhouse gas emissions, the direct consequences of climate change and its impacts on human health, food and water security, and socioeconomic systems will become irreversible (1,2).

One of the major sources of greenhouse gas emissions is the food industry. The global food system, including land use, supply chains, refrigeration, and consumption, is responsible for approximately one-quarter to one-third of global greenhouse gas emissions (3,4). Animal-based products contribute significantly to these emissions. Estimates suggest that 57% of food-related greenhouse gas emissions originate from animal products, while plant-based foods account for only 29% (5). Nevertheless, meat and other animal products remain a fundamental part of many diets, particularly in Western countries (6). To mitigate their environmental impact, more sustainable dietary patterns have been proposed, such as the Planetary Health Diet, which has become the global reference for a sustainable diet (7–9). This dietary pattern is primarily based on fruits and vegetables, whole grains, legumes, nuts, and unsaturated fats, complemented by moderate amounts of fish and poultry. In contrast, starchy vegetables, dairy products, red meat, sugar, and saturated fats play a minor role (9).

A shift in average dietary patterns in Germany toward a predominantly plant-based diet could yield substantial environmental and public health benefits. Studies have indicated that a vegetarian diet could reduce food-related greenhouse gas emissions by 20% to 47%, while a vegan diet could lead to a reduction of 38% to 52% (10). On a global scale, such a shift could even result in emission reductions of 60% to 70% (11). Beyond ecological advantages, plant-based diets offer significant health benefits; they have been associated with a reduced risk of noncommunicable diseases, such as type 2 diabetes, cardiovascular diseases, and various types of cancer, and a decrease in overall mortality (9,12–14). The combination of healthy, sustainable dietary choices and the transformation of food systems is therefore essential in mitigating both climate change and the increasing prevalence of chronic diseases.

However, the amount of food consumed in Germany differs significantly from recommendations for a sustainable diet (15). In particular, the intake of vegetables, fish, and oils is well below the recommended levels, whereas the consumption of meat—especially red meat—and sugar is considerably higher (15). Researchers have identified numerous reasons why consumers struggle to align their eating habits with sustainability goals, one of which is a lack of knowledge about the environmental impact of food production and consumption (16–18). Studies have shown that consumers often fail to accurately assess the environmental impact of their food choices (19). They underestimated the environmental burden of meat products, particularly organically and domestically produced meat, as well as vegetarian, protein-rich products. At the same time, they overestimated the impact of packaging, transport distances, and conventionally produced food (20–22). A key approach to transforming the food system is therefore to raise consumer awareness of sustainable food choices (23).

To achieve a shift toward healthy, sustainable diets, the literature, among other things, highlights the enhancement of consumer education and awareness through clear and simple communication (24). Comprehensive knowledge is considered a key prerequisite for behavioral change, as it can enhance understanding of the issue and positively influence attitudes (25). Studies have shown that individuals with higher environmental awareness were more likely to make eco-friendly choices and were more willing to reduce their meat consumption for environmental reasons (6,22,23,26). Although increased environmental awareness does not necessarily lead to sustainable behavior—since situational, socioeconomic, or structural factors, such as product availability, can influence its effectiveness—it remains a crucial prerequisite for changing attitudes and behavioral intentions (25,27). Moreover, it can serve as a precursor to the acceptance of more invasive measures, such as higher taxes, bans, or regulatory requirements (28).

More recently, gamification has gained traction in the field of environmental sustainability (29), and research suggests that gamification can increase players' awareness and understanding of how their actions impact the environment (27,30). However, there is a lack of studies specifically addressing sustainable nutrition (31) and studies grounded in theoretical frameworks, although theory-based games have been shown to be more effective (27,32,33).

Therefore, in this study, we aimed to increase knowledge about the environmental impact of food in an easily comprehensible manner. To achieve this, we developed a gamified quiz and used the Transtheoretical Model (TTM) to assess the role of prior knowledge and readiness for change. The participants' knowledge significantly increased after the quiz, especially among those with low prior knowledge. Readiness for change, as measured by the TTM, showed no effect on prior knowledge or knowledge gain.

2 Hypotheses

To gain an overview of the current state of research on gamification, we conducted a systematic literature review regarding the use of game-based learning in the context of sustainability. We included 16 observational studies or randomized controlled trials published between 2014 and 2024 with changes in knowledge, understanding, or awareness as outcomes. The search string and the literature selection process are documented in the supplement (S1 Table, S1 Figure).

A key advantage of gamification is its potential to enhance learner engagement and promote long-term knowledge retention more effectively than traditional paper-based learning methods (32). Interactive and game-based learning methods such as quizzes (a) foster intrinsic motivation and enable players to actively assess and consolidate their knowledge (33), (b) promote the reflection process, which is considered an important link between learning and knowledge, and (c) support long-term knowledge retention (34). Therefore, we expected that the quiz format in this study would increase participants' knowledge of ecologically sustainable diets:

H1 (Quiz Hypothesis): *Participants will show significantly higher knowledge about ecologically sustainable diets after completing the quiz than before participating.*

In cognitive psychology, prior knowledge is considered a key factor in the learning process. Learners with extensive prior knowledge process new information more efficiently because they can integrate it better into existing knowledge networks (35). Studies have shown that learners with higher prior knowledge tend to perform better on tests (36). Therefore, it is expected that participants with higher prior knowledge will achieve better results in this studies' quiz:

H2 (Prior Knowledge Hypothesis): *The higher the participants' prior knowledge of ecologically sustainable diets, the more quiz questions they will answer correctly.*

Additionally, the relationship between prior knowledge and improvement potential in the knowledge test will be examined. Learners with lower prior knowledge tend to achieve greater knowledge gains because they have more room for improvement (37). Therefore, we expected that participants with lower prior knowledge would benefit more from the quiz:

H3 (Prior Knowledge Improvement Hypothesis): *Participants with lower prior knowledge of ecologically sustainable diets will show greater improvement in their knowledge than participants with high prior knowledge.*

Research on the TTM suggests that individuals in the early stages of behavior change have a lower awareness of the environmental impacts of dietary patterns and are therefore less likely to implement sustainable eating recommendations (38,39). On the other hand, individuals in later stages show greater awareness and adapt their eating habits accordingly (40–42). This suggests that prior knowledge of sustainable diets will correlate with the stage of behavior change according to the TTM:

H4 (Stage Hypothesis): *The further the behavior change stage in the Transtheoretical Model, the higher the participants' prior knowledge of ecologically sustainable diets.*

Additionally, Prochaska and Velicer (43) emphasized that stage-based interventions are critical for successful behavior change. Individuals in the early stages particularly benefit from interventions that raise awareness of the consequences of their behaviors, while individuals in the advanced stages require support in implementing and maintaining new behaviors (44). It is therefore expected that participants in the early stages of the TTM will respond more strongly to the quiz:

H5 (Stage Improvement Hypothesis): *Participants in the early stages of the Transtheoretical Model will show greater improvement in their knowledge than participants in the advanced stages.*

All hypotheses have been preregistered in the spirit of Open Science and can be accessed at: [https://osf.io/m4xnz/?view_only=b858910b5fba44418223167889ce1280].

3 Materials and Methods

The study had a quasi-experimental, mixed-subject design: the within-subject factor time with two measurement points (pre- and post-quiz) and the between-subject factor TTM group following the three stages of readiness to adopt sustainable eating habits: (1) precontemplation/contemplation, (2) preparation, and (3) action/maintenance according to Culliford and Bradbury (40). Full measurements and the questionnaire are openly available on OSF [https://osf.io/m4xnz/?view_only=b858910b5fba44418223167889ce1280].

3.1 Sample and Data Collection

Data collection took place between 26.06.2024 and 31.07.2024 via an online questionnaire (EFS survey by Questback). Participants were recruited via social media (Instagram, Facebook, and LinkedIn) and research platforms (SurveyCircle and PollPool). We excluded participants who (1) did not complete the full survey, (2) were younger than 18 years, or (3) failed the attention check, resulting in a final sample of $N = 338$ participants. An a priori power analysis for repeated measures analysis of variance (ANOVA) (G*Power; (45)) indicated a required sample size of $N = 294$ (power = 0.8, alpha = 0.05, effect size f = 0.1).

The participants' mean age was $M = 34.2$ ($SD = 12.7$, [18-78]); 63.9% were female. The majority (83.5%) had at least 10 years of schooling with qualifications for higher education. The participants indicated the following dietary habits: omnivore (34.6%), flexitarian (34.3%), vegetarian (16.0%), flexigan (8.0%), and vegan (7.1%).

3.2 Measurements

To group participants according to the stages of the TTM, we measured their *readiness to adopt sustainable eating behaviors* using an adapted version of the TTM measure by Weller (46). The participants rated five behaviors based on the British Dietary

Association guidelines for a sustainable diet: (1) buying locally grown produce, (2) avoiding excessive packaging, (3) avoiding air-freighted food, (4) consuming seasonal produce, and (5) limiting meat consumption to 1–2 times per week. Response options ranged from 1 = *not considering it* (precontemplation) to 5 = *doing it most of the time* (maintenance), reflecting the TTM phases (47). Item 5 was excluded to improve scale reliability (Cronbach's alpha = 0.69). Due to low response rates in several stage categories, the five stages of change were combined into three for statistical analysis: precontemplation and contemplation, preparation, and action and maintenance.

The participants' *knowledge about sustainability and nutrition* was assessed with 10 single-choice questions; 5 adapted from the literature (26,47,48) and 5 developed to address missing content. Questions assessed both system knowledge (e.g., "What does the term carbon footprint mean?") and action-related knowledge (e.g., "Which of the following diets is ecologically sustainable?"). Questions were arranged with increasing difficulty. Correct answers earned one point, and incorrect answers earned zero points. To minimize recall effects, a parallel set of items was used for the post-test with randomized answer choices to prevent response biases. Constructed and parallel items are displayed in the supplement (S2 Table).

3.3 Intervention: The Quiz

We developed an interactive quiz on the environmental impact of various food groups to enhance knowledge about sustainable nutrition and encourage reflection. The quiz content was based on scientific calculations of food-related environmental impacts (50,51) and incorporated multimedia, game-based, and motivational elements, as recommended by Abdul Jabbar and Felicia (52).

The quiz comprised three sections:

1. *Introduction*: Explanation of the learning objective and game rules (e.g., option to skip or revisit questions).
2. *Main Part*: An interactive quiz in which participants selected the food item with the lowest or highest carbon footprint from three choices. The quiz covered six categories: (1) product type (plant-based vs. animal-based), (2) seasonality (seasonal vs. non-seasonal), (3) regionality (regional vs. non-regional), (4) import type (ship vs. air freight), (5) dish type (vegan vs. omnivore), and (6) beverage packaging (returnable glass bottles vs. composite cartons). Category 1 included two questions, while each of the other categories included one question, resulting in a total of seven questions. To enhance comprehension, CO_2 equivalents were color-coded (green for low emissions and red for high) (53). The participants earned one point for each correct response and received immediate feedback to support learning (54).
3. *Conclusion*: The participants were assigned a knowledge level based on their score: Knowledge Discoverer (≤3 points), Knowledge Builder (4–5 points), or Knowledge Master (≥6 points). This digital badge served as a motivational reinforcement (55,56).

The quiz in its original German version can be found in the OSF (https://osf.io/m4xnz/?view_only=b858910b5fba44418223167889ce1280).

3.4 Pilot Study

A pilot study with 32 German-speaking adults (M = 43.3, SD = 15.4, [22–72]) was conducted via convenience sampling of messenger services. Items with poor difficulty (>80% correct responses) or discrimination (<0.2 item-total correlation) were revised. Item difficulty and discrimination and the revised versions are displayed in the supplement (S2 Table, S3 Table). The final test had acceptable internal consistency (Cronbach's alpha = 0.72).

3.5 Statistical Analysis

All analyses were performed using R Studio (R version 4.3.2 (2023-10-31). Raw data and analysis scripts are available on OSF (https://osf.io/m4xnz/?view_only=b858910b5fba44418223167889ce1280).

3.6 Ethical considerations

Ethics approval was obtained from the Research Ethics Board of the University of Erfurt. At the beginning of the questionnaire, the respondents were informed about the study, data protection policies, their right to withdraw at any time without consequences, and the voluntary nature of their participation. Written informed consent was obtained from the respondents before they began the questionnaire.

4 Results

Hypothesis H1 posits that participants' knowledge scores are significantly higher after completing the quiz than before. This assumption was tested using a one-sided paired t-test, with knowledge score as the dependent variable and measurement time point (pre-/post-quiz) as the independent variable. The paired t-test confirmed a significant increase in knowledge scores after the quiz ($M = 7.64$, $SD = 1.72$) compared to before ($M = 6.78$, $SD = 1.67$), $t(337) = 9.79$, $p < .001$, $d = .50$, 95% CI [.40, .61]. The effect size indicates a moderate effect (57).

To test Hypothesis H2, which posits that higher prior knowledge is associated with higher quiz scores, a linear regression analysis was conducted. The quiz score served as the dependent variable, while the prior knowledge score was the independent variable. The regression model was statistically significant and explained a moderate proportion of the variance in quiz scores, $R^2 = .15$, $F(1{,}336) = 60.54$, $p < .001$. Prior knowledge was a significant predictor of quiz performance, $B = .30$, $t(336) = 7.78$, $p < .001$, confirming Hypothesis H2.

To examine the additional association between prior knowledge and age, gender, education, and dietary habits, an exploratory multiple regression analysis was conducted. This model was also significant, $R^2 = .18$, $F(9,318) = 7.35$, $p < .001$. Prior knowledge remained a significant predictor ($B = .29$, $t(332) = 6.50$, $p < .001$), whereas age ($B = .01$, $t(332) = 1.39$, $p = .165$), gender ($B = .16$, $t(332) = 1.04$, $p = .299$), education (e.g., high education $B = .24$, $t(332) = 2.87$, $p = .408$), and dietary habits (e.g., vegan diet: $B = .38$, $t(332) = 1.31$, $p = .192$) did not show significant correlations with prior knowledge. These additional factors thus do not appear to substantially predict quiz performance, suggesting that other factors may be relevant. Both models are displayed in Table 1.

Table 1

Linear Regression Analysis for Hypothesis 2 (Model 1) and Exploratory Multiple Regression Analysis Including Further Predictors

	Quiz Knowledge Model 1			Quiz Knowledge Model 2		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	2.81	2.28 – 3.34	<.001	2.74	1.89 – 3.60	<.001
Prior Knowledge	0.30	0.22 – 0.38	<.001	0.29	0.20 – 0.37	<.001
Age				0.01	-0.00 – 0.02	.165
Gender				0.16	-0.14 – 0.45	.299
Education middle (vs. low)				-0.34	-0.91 – 0.23	.245
Education high (vs. low)				-0.24	-0.80 – 0.33	.408
Vegetarian (vs. omnivore)				0.36	-0.06 – 0.78	.092
Vegan (vs. omnivore)				0.38	-0.19 – 0.96	.192
Flexitarian, mainly veggie (vs. omnivore)				-0.01	-0.33 – 0.32	.973

Flexigan, mainly vegan (vs. omnivore)				0.22	-0.33 – 0.76	.432
Observations	338			328		
R^2 / R^2 adjusted	0.153 / 0.150			0.176 / 0.153		

Hypothesis H3 suggests that participants with lower prior knowledge experience a greater increase in knowledge scores through the quiz compared to those with higher prior knowledge. To examine this association, a 2 × 3 mixed-design ANOVA with repeated measures was conducted, with measurement time point (pre-/post-quiz) as the within-subject factor and prior knowledge group (low, moderate, high) as the between-subject factor. The prior knowledge groups (each n >15) were defined as follows: low prior knowledge (M = 4.33, SD = 0.81), moderate prior knowledge (M = 6.49, SD = 0.50), and high prior knowledge (M = 8.52, SD = 0.66).

The ANOVA results can be seen in Table 2. The results revealed a significant interaction between the measurement time point and the prior knowledge group, $F(2,333) = 35.65$, $p < .001$, partial $\eta^2 = .08$. The Games–Howell post hoc test indicated significant differences in knowledge gains between all groups ($p < .001$), with the largest increase observed in the low prior knowledge group. These findings suggest an association between lower prior knowledge and greater increases after quiz performance, supporting Hypothesis H3. Figure 1 shows the interaction between prior knowledge text values and test improvement.

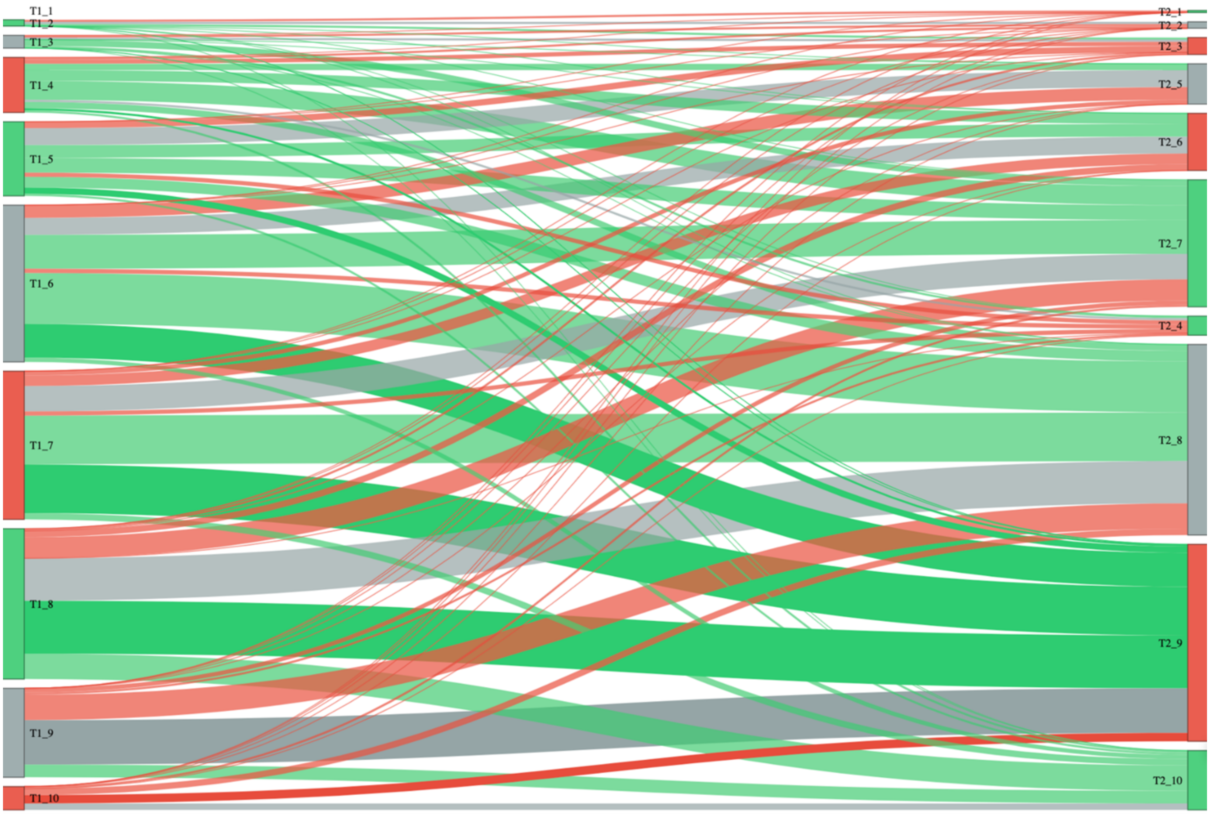
Table 2

ANOVA Results for Knowledge Pre- and Post-Quiz Intervention

Effect	**Dfn**	**Dfd**	**MSE**	***F***	**ges**	***p***
Knowledge groups	2	335	1.459	350.195	0.548	<.001
Time	1	335	1.062	130.071	0.141	<.001
Knowledge groups * Time	2	335	1.062	35.649	0.082	<.001

Figure 1

Changes in Knowledge Sum Scores from Prior (left) to Post-Quiz (right)



Note. Every line from left to right represents a participant. Green lines indicate an increased knowledge sum score, and red lines indicate a decrease in knowledge sum scores. Gray lines represent the same sum score before and after the quiz. The interaction effect from the ANOVA to test H3 suggests an association between lower prior knowledge and greater increases after quiz performance.

To test Hypothesis H4, which posits that participants' prior knowledge increases with the stage of readiness for change according to the TTM, a one-way 3 × 1 ANOVA was conducted. In this analysis, prior knowledge served as the dependent variable, while the TTM stages were treated as the independent variable. The TTM stages were grouped into three categories (each $n > 15$): precontemplation/contemplation ($M = 7.06$, $SD = 1.06$), preparation ($M = 6.99$, $SD = 1.54$), and action/maintenance ($M = 6.71$, $SD = 1.74$). The ANOVA revealed no significant differences in prior knowledge across the TTM stages, $F(1, 336) = 1.88$, $p = .171$, partial $\eta^2 = .006$. Since the assumptions for ANOVA were violated, a more robust Kruskal–Wallis test was conducted for validation. This test also showed no significant differences in rank distributions across the groups (each Mdn = 7.00), $H(2) = 1.57$, $p = .457$, $r = .09$. Figure 2 illustrates the confidence intervals, distributions, and boxplots for the three groups in the ANOVA.

Subsequently, the potential associations between prior knowledge and the factors of age, gender, and dietary pattern were examined. Table 3 shows the results of an ANCOVA, controlling for age, gender, education, and nutrition.

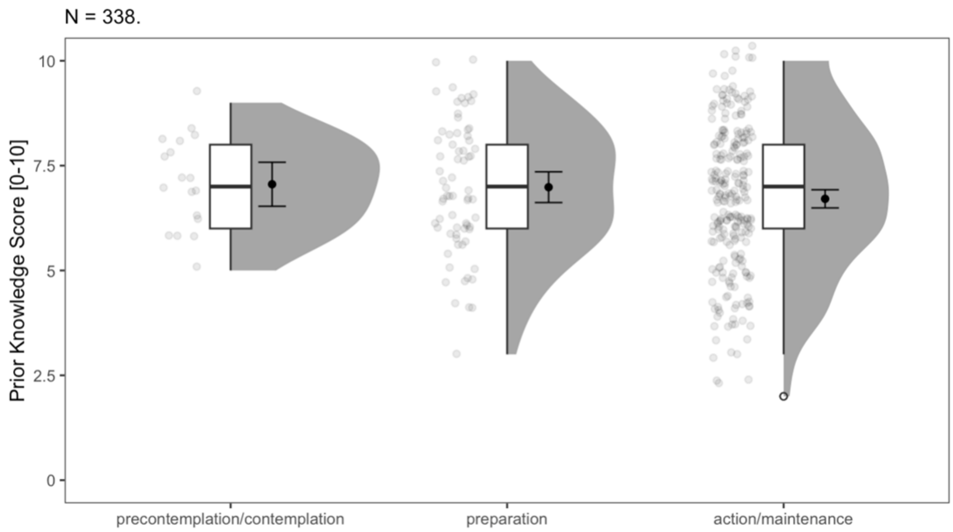
Table 3

ANCOVA Results for Prior Knowledge

Effect	**DFn**	**DFd**	***F***	***p***	**η^2**
TTM Categories	1	318	2.298	.131	.007
Age	1	318	0.512	.475	.002
Gender	1	318	11.499	<.001	.035
Education	2	318	6.998	.001	.042
Nutrition	4	318	9.396	<.001	.106

Figure 2

Hypothesis 4: Confidence Intervals, Distributions, and Boxplots for the Three Groups in the ANOVA



To examine whether participants in lower TTM stages show greater improvement through quiz participation compared to those in higher TTM stages (Hypothesis H5), a 2 × 3 mixed-design ANOVA with repeated measures was conducted. The measurement time point (pre-/post-quiz) was modeled as the within-subject factor, while the TTM stages (precontemplation/contemplation, preparation, and action/maintenance) served as the between-subject factor. The ANOVA results can be seen in Table 4 and revealed no significant interaction between measurement time points and the TTM stage groups, $F(2, 335) = 0.46$, $p = .634$, partial $\eta^2 = .00$. However, a significant main effect of time was observed, $F(1, 335) = 35.76$, $p < .001$, partial $\eta^2 = .10$, indicating overall improvement in knowledge following the quiz. The main effect of the group was not significant, $F(2, 335) = 2.00$, $p = .137$, partial $\eta^2 = .01$.

Table 4

Mixed-Measurement ANOVA Results for Knowledge over Time

Effect	Dfn	Dfd	MSE	*F*	ges	*p*
TTM Categories	2	335	4.455	1.996	0.0092	0.137
Time	1	335	1.284	35.762	0.0233	<.001
TTM Categories * Time	2	335	1.284	0.456	0.0006	0.634

5 Discussion

The aim of this study was to examine whether a gamified online intervention promoting environmentally sustainable nutrition could increase participants' knowledge. For this purpose, a quiz format was developed and tested, considering prior knowledge and readiness for change according to the TTM.

After completing the quiz, the participants' knowledge increased, indicating that participation in the quiz led to a measurable improvement in their knowledge about environmentally sustainable diets. Misconceptions regarding seasonality, origin, transportation, and packaging were largely corrected, as reflected in the higher proportion of correct answers to these questions.

The results highlight the key role of prior knowledge in the effectiveness of the quiz. The participants with higher baseline knowledge scored higher overall, but the greatest increase in knowledge was observed among the participants with low prior knowledge. This suggests that participants with limited prior knowledge benefited more from the quiz, whereas those with higher prior knowledge may have reached a saturation point.

In contrast, readiness for change according to the TTM did not significantly influence prior knowledge or knowledge gain. Thus, the quiz proved equally effective, regardless of the stage of behavioral change.

The knowledge about environmentally sustainable diets in this study's sample was higher than in other studies. In a 2021 study, respondents correctly answered an average of 50% of the questions on a sustainability knowledge scale (58). A follow-up study in 2024 reported an average of 55.8% (59). The higher knowledge levels in the present study could be attributed to the scale used or the sample investigated, as it primarily included employed individuals with an academic background, whereas the studies by Bloyd Null et al. (58) and Null et al. (59) focused on students. It should also be considered that consumer awareness has evolved rapidly in recent years (60). Studies examining gender differences have shown mixed results. Unlike this study, Svendsen et al. (61) found higher sustainability concept understanding among women, while Younes (62) found no significant gender differences.

The present study demonstrated a significant increase in knowledge about sustainable diets after the participants completed the quiz. This is in line with two studies that also show that playful informational measures effectively enhance environmental knowledge. Soma et al. (63) investigated an online quiz aimed at raising awareness of food waste, which, similar to the developed quiz, incorporated gamification elements, such as points and rewards. They found that the quiz increased awareness and contributed to a reduction in food waste, particularly among regular players. Null et al. (59) also reported a significant increase in knowledge among students following a multifaceted awareness campaign that included posters, videos, and a knowledge quiz. Additionally, the campaign helped reduce red meat consumption.

While the positive effects on knowledge were similar across all studies, differences in study design and target behaviors limited the direct comparability of the results. Both aforementioned studies spanned several weeks and examined both knowledge and behavioral changes, whereas the present study tested the effectiveness of a one-time intervention on knowledge alone.

Similar to the present study, Bröder et al. (37) showed that prior knowledge influences learning success. They tested a seeding intervention in which participants provided CO_2 estimates for foods and then received feedback. This improved the estimates for both familiar (seeding items) and new foods (transfer items). In both studies, participants with low prior knowledge benefitted more from the intervention than those with higher prior knowledge.

Another key finding in the present study was the general effectiveness of the quiz across all phases of the TTM. Similarly, the Green Eating Project showed that participants' knowledge significantly increased after a web-based intervention aimed at promoting environmentally conscious eating behaviors, even without a stage-based design (39). The participants shifted from earlier to later TTM stages, suggesting that knowledge gain is possible even without a stage-based approach and may potentially influence readiness for change.

5.1 Limitations

The simplification of the TTM constructs into 3 phases instead of 5 in this study represents a departure from the original theory. Since we are working with potential information loss, we must assume that the results likely understate rather than overstate the effects. As the data collection was based on self-reports, there is a risk that the responses do not realistically reflect actual behavior and may, for example, be biased by social desirability. The participants might present their willingness to engage in sustainable behavior more positively than it truly is in order to meet societal expectations. The statistical power may be limited, particularly for subgroup analyses (e.g., by age or gender), even though the recommended sample size of 294 participants was achieved. This carries the risk of undetected effects.

The sample consisted predominantly of young women with academic backgrounds. In this demographic group, knowledge about and interest in sustainable diets may be overrepresented, which limits the generalizability of the results to other population groups (e.g., different educational levels or age groups). Future research should therefore aim for larger and more representative samples from various socioeconomic groups and age ranges, possibly using random or stratified sampling methods. Studies conducted in different cultural contexts could also help identify differences in attitudes and behaviors, thereby improving the generalizability of the results.

No conclusions can be drawn about whether the acquired knowledge is retained long-term or whether it contributed to a change in behavioral intentions or actual behavior. Future studies could employ longitudinal designs to track the effects of the intervention over several months and to assess long-term knowledge retention. Additionally, they could capture actual behavior (e.g., purchasing patterns) to better understand the relationship between knowledge and behavior and analyze whether and how knowledge leads to more sustainable behavior.

5.2 Conclusion

The findings of this study emphasize the potential of gamification to raise awareness about the environmental impacts of dietary choices. To date, no other studies have explicitly investigated the effectiveness of stage-based interventions on knowledge increases in the context of sustainable diets. Most studies in this area have focused on sustainable behaviors, such as conserving energy and water, reducing pollution and CO_2 emissions, or improving transportation and air quality (27,30). In contrast, the field of sustainable nutrition has received little attention so far (31). This study is therefore a first step in research on gamified learning in the context of sustainability and nutrition, and it thus lays a valuable foundation for further research. Future studies should include larger and more diverse samples, employ broader and more validated measurement tools, and examine the long-term effects on behavior. Exploring various game formats and elements, as well as combining gamification with other behavioral change models, could provide new insights and further enhance the effectiveness of game-based interventions in promoting sustainable diets.

Advances in this area could be applied to support sustainable dietary education in practice. In educational settings, interactive formats, such as the developed quiz, could be integrated into environmental curricula to raise awareness among young people about the ecological impact of their food choices. In the healthcare sector, the quiz could be used as a tool in preventive nutrition counseling, helping professionals educate individuals about healthy eating and its connection to climate change. Such applications have the potential not only to promote individual health but also to foster more sustainable consumption habits at a societal level. Policymakers, in turn, could incorporate such tools into educational initiatives or national campaigns aimed at reducing carbon emissions in the food sector.

Acknowledgments

Generative AI Statement

The authors used ChatGPT (v. 4.0) for language consultation (checking for grammar and precision), as well as to generate an R code commentary to make the code replicable and increase understanding of the procedure.

Data Availability Statement

Data and analysis scripts are available under the link:
https://osf.io/m4xnz/?view_only=b858910b5fba44418223167889ce1280

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Ethics approval and consent to participate

The participants gave consent to participate and were informed that they could terminate their participation at any time. The survey was conducted in accordance with the Declaration of Helsinki, and materials and protocols were approved by the ethical review board from the University of Erfurt.

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