Research article

Environmental Psychology Open

An Experimental Approach to Assess the Impact of Three Environmental Knowledge Types on Food-Related Behavioral Intentions and Choices

Ein experimenteller Ansatz zur Untersuchung der Auswirkungen der drei Umweltwissensformen auf ernährungsbezogene Verhaltensabsichten und -entscheidungen

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Author statement

DM: Conceptualization, Methodology, Software, Investigation, Formal analysis, Data curation, Writing - original draft, Writing - review and editing. MKL: Conceptualization, Methodology, Writing - original draft, Writing - review; FS: Formal analysis; Writing - original draft, Writing - review; ME: Conceptualization, Methodology, Writing - original draft, Writing - review. Conflicts of interests: none.

We thank Simply Toast in Kassel for their collaboration with vouchers for their restaurant. We are also grateful for Vantastic Foods and Hachez who supported the study by donating vegan and milk chocolate. We thank Maria-Christina Weber, Valerie Weber, and Anna Helfers for their support in conducting the study and data processing.

Mundt, D., List, M. K., Scharf, F. & Ebersbach, M. (2026). An Experimental Approach to Assess the Impact of Three Environmental Knowledge Types on Food-Related Behavioral Intentions and Choices. *Environmental Psychology Open, 30,* Article 34. https://doi.org/10.69805/epo.v30.a34

Submitted 19 May 2025, accepted 22 January 2026, published 24 February 2026. Handling editor: Andreas Homburg
ISSN: 2943-7768

Abstract

Effective environmental education requires the identification of relevant learning content. Correlational evidence suggests that different environmental knowledge types influence behavior. We explored this experimentally, assigning N = 304 university students to five conditions where they read texts imparting: (1) a moderate amount of *system knowledge*, (2) a moderate amount of *system and action-related knowledge*, (3) a moderate amount of *system, action-related and effectiveness knowledge*, (4) a *high amount of system knowledge only,* and (5) *environment-unrelated knowledge*. We then measured participants' intention to consume animal products (operationalized by CO_2 emission score in kg) and their actual consumption behavior (i.e., choosing between vouchers for vegan, cheese, chicken, or beef sandwiches and between vegan or milk chocolate bars). Assessed covariates were participants' pre-intervention consumption of animal products and affinity for animal products. Results indicate no statistical differences between the different environmental knowledge types on participants' consumption intentions and actual behavior. However, compared to *environment-unrelated knowledge,* the intention was lower for *system, action-related and effectiveness knowledge* (adj. Cohen's d = 0.52, 95% CI [0.16, 0.87]) and *high amount of system knowledge* only (adj. Cohen's d = 0.59, 95% CI [0.23, 0.85]). We discuss the need for further experimental approaches in environmental knowledge research.

Keywords

environmental knowledge, system knowledge, action-related knowledge, effectiveness knowledge, sustainable dietary behavior

Impact statement

In a text-reading experiment we examined how different types of environmental knowledge (i.e., system, action-related, and effectiveness knowledge) influence participants' intention to consume animal products and their actual consumption behavior. We hypothesized that the intended consumption of animal products (operationalized by CO_2 emission score in kg) depends on the particular knowledge type with the strongest effects for effectiveness knowledge. Results showed that participants who were presented with either all three knowledge types or a high amount of system knowledge only, reported stronger intentions to reduce consumption. Actual consumption behavior did not differ across experimental conditions. The findings highlight the importance of both the quality and the quantity of environmental knowledge for promoting pro-environmental behavioral intentions. Our experimental setup can serve as a valuable tool to further investigate if different knowledge types affect pro-environmental intentions and behavior. Thus, it can help to determine whether the type or the amount of knowledge is more critical for designing effective interventions.

Zusammenfassung

Wirksame Umweltbildung erfordert die Identifizierung relevanter Lerninhalte. Korrelationsergebnisse weisen darauf hin, dass verschiedene Umweltwissensformen Verhalten unterschiedlich beeinflussen. Wir haben dies experimentell untersucht, indem $N = 304$ Universitätsstudierende fünf Textbedingungen zugewiesen wurden, in denen das folgende Wissen vermittelt wurde: (1) ein moderates Maß an Systemwissen, (2) ein moderates Maß an System- und Handlungswissen, (3) ein moderates Maß an System-, Handlungs- und Wirksamkeitswissen, (4) ein hohes Maß an Systemwissen und (5) umweltunbezogenes Wissen. Nach dieser Leseintervention erfassten wir die Intention der Teilnehmenden, tierische Produkte zu konsumieren (operationalisiert über einen CO_2-Emissioswert in kg), und ihr tatsächliches Konsumverhalten (d.h., die Wahl zwischen Gutscheinen für vegane, Käse-, Hühner- oder Rindfleischsandwiches und zwischen veganer oder Milchschokolade). Als Kovariaten dienten der Konsum tierischer Produkte vor der Intervention und die Affinität der Teilnehmenden zu tierischen Produkten. Für die Wahl von Sandwich und Schokolade zeigten sich keine statistischen Unterschiede zwischen den verschiedenen Umweltwissensformen. Im Vergleich zur umweltunbezogenen Wissensbedingung war die Konsumintention bei Teilnehmenden in der System-, Handlungs- und Wirksamkeitswissensbedingung (adj. Cohen‘s d = 0.52, 95% *CI* [0.16, 0.87]) sowie in der Bedingung mit einem hohen Maß an Systemwissen (adj. Cohen‘s d = 0.59, 95% *CI* [0.23, 0.85]) geringer. Der Bedarf an weiteren experimentellen Ansätzen in der Umweltwissensforschung wird diskutiert.

Schlüsselwörter

Umweltwissen, Systemwissen, Handlungswissen, Wirksamkeitswissen, nachhaltiges Ernährungsverhalten.

Impact-Statement

In einem Textlese-Experiment untersuchten wir, wie sich unterschiedliche Umweltwissensformen (d. h. System-, Handlungs- und Wirksamkeitswissen) auf die Intention der Teilnehmenden auswirken, tierische Produkte zu konsumieren (operationalisiert über einen CO_2-Emissionswert in kg), und wie sie tatsächliche Konsumentscheidungen beeinflussen. Wir erwarteten, dass der beabsichtigte Konsum von tierischen Produkten von der jeweiligen Wissensart abhängt, wobei wir die stärksten Effekte für das Wirksamkeitswissen erwarteten. Die Ergebnisse zeigten, dass Teilnehmende, denen entweder alle drei Wissensarten oder ausschließlich eine große Menge an Systemwissen präsentiert wurden, stärkere Intentionen äußerten, ihren Konsum zu reduzieren. Hinsichtlich der tatsächlichen Konsumentscheidungen zeigten sich keine Unterschiede zwischen den Bedingungen. Die Befunde sprechen sowohl für die Bedeutung der Qualität als auch der Quantität von Umweltwissen für umweltfreundliche Verhaltensabsichten. Unser experimentelles Design kann als wertvolles Instrument dienen, um weiter zu untersuchen, ob unterschiedliche Wissensarten umweltfreundliche Intentionen und Verhaltensweisen beeinflussen. So kann ermittelt werden, ob für die Gestaltung wirksamer Interventionen eher die Art oder die Menge des vermittelten Wissens entscheidend ist.

1 Introduction

Climate change poses an imminent threat to both the environment and human health and requires urgent action to curb anthropogenic greenhouse gas emissions at all levels (Intergovernmental Panel on Climate Change, 2023). In response to these challenges, educational initiatives and programs have been developed with the aim of raising learners' awareness and motivation for pro-environmental engagement (UNESCO, 2014, 2017; Varela-Losada et al., 2016, Wals et al., 2008), with knowledge transfer being a central component within these educational approaches (Perrenoud, 2010). Therefore, to design environmental education programs that can effectively support pro-environmental behavior, it is essential to determine which knowledge content is most influential.

In the literature, different types of environmental knowledge[1] (i.e., system, action-related, and effectiveness knowledge) have been proposed to affect pro-environmental behavior in distinct ways (Frick et al., 2004; Kaiser et al., 2008; Roczen et al., 2014). However, empirical evidence for these knowledge types and possible effects on pro-environmental behavior is weak (e.g., Geiger et al., 2019). The present study offers a first step to fill this research gap by experimentally investigating the effects of these three types of environmental knowledge, transferred through informational texts, on participants' pro-environmental intentions and actual behaviors. To our knowledge, our study is the first to examine effects of environmental knowledge types in an experimental setting (Player et al., 2023), providing valuable insights into the causal relationship between environmental knowledge and individuals' behaviors, which can inform the development of effective educational interventions.

1.1 Environmental knowledge

Environmental knowledge reveals the problematic impact of human actions on the planet earth, like climate change or loss of biodiversity (e.g., Frick et al., 2004; Kaiser & Fuhrer, 2003; Kaiser et al., 2008). Several studies have demonstrated a link between environmental knowledge and behavior (e.g., Geiger et al., 2018; Levine & Strube, 2012; Vicente-Molina et al., 2013). Environmental knowledge is an intellectual prerequisite for conscious behavior change, as it fosters an understanding of environmental issues that motivates individuals to protect the environment (Fremerey & Bogner, 2014; Geiger et al., 2019; Kaiser et al., 2008; Roczen et al., 2010).

When promoting pro-environmental behavior through environmental knowledge, a specific underlying structure of environmental knowledge was proposed as being essential: system knowledge, action-related knowledge, and effectiveness knowledge (Frick et al., 2004; Kaiser & Fuhrer, 2003; Kaiser et al., 2008; Roczen et al., 2014). System knowledge, also referred to as ecological knowledge (Ernst, 1994), entails declarative knowledge about the ecosystem and the origin of environmental problems (Frick et al., 2004; Kaiser et al., 2008). Action-related

[1] In this study, we speak of environmental knowledge types, which are also referred to as environmental knowledge dimensions in previous studies.

knowledge entails knowledge about available behavior options for conserving the environment (Kaiser & Fuhrer, 2003; Kaiser et al., 2008). Effectiveness knowledge informs about the environmental impact of specific actions (Kaiser et al., 2008).

Results of Frick et al.'s (2004) questionnaire study suggested that system knowledge only indirectly affects environmental behavior through its impact on action-related and effectiveness knowledge, both of which directly predict pro-environmental behavior. Thus, system knowledge provides reasons for searching for appropriate behavior options to resolve the presented environmental problems but might not be sufficient to affect behavior directly (Roczen et al., 2010). Consequently, action-related knowledge and effectiveness knowledge build on system knowledge (Liefländer et al., 2015), with effectiveness knowledge helping to select the most effective behavioral option based on action-related knowledge, which offers various behavioral options (Kaiser et al., 2008). No influence of effectiveness knowledge on the other environmental knowledge type was suggested (Roczen et al., 2010).

Although theoretically convincing, the empirical evidence for the differentiation of these environmental knowledge types is weak and contradictory. While Frick et al. (2004) confirmed the multifaceted structure, results of Geiger et al. (2019) and Kaiser and Frick (2002) support a one-dimensional construct. Player et al. (2023) found evidence for both, a one- and multidimensional environmental knowledge construct. Other studies that based their theory and methodology on the three types did not explicitly examine the structure nor contrasted them (Baierl et al., 2022; Braun & Dierkes, 2017; Fremerey & Bogner, 2014; Geiger et al., 2014; He et al., 2022; Kolenatý et al., 2022; Liefländer et al., 2015; Maurer & Bogner, 2020; Roczen et al., 2014). Moreover, the majority of studies relies on a correlative approach (e.g., Frick et al., 2004; He et al., 2022; Player et al., 2023; Polonsky et al., 2012), which makes it difficult to draw causal conclusions. Further, these studies were often based on participants' self-reported knowledge, without ensuring that participants possessed (correct) environmental knowledge (e.g., Frick et al., 2004; He et al., 2022; Roczen et al., 2014). This issue is problematic because action-related, and especially effectiveness knowledge is underrepresented among people (Braun & Dierkes, 2017; Fremerey & Bogner, 2014; Frick et al., 2004; Morren et al., 2021; Truelove & Parks, 2012). Thus, interpretations concerning the influence of the specific knowledge types remain vague. To address the research gaps regarding environmental knowledge, with this study, we are providing a first experimental attempt to investigate if the three environmental knowledge types proposed in the literature have different (if any) effects on behavioral variables. In this way, we aim to establish causal evidence for the multifaceted structure of environmental knowledge.

1.2 The present study

To provide valuable insights for educational practice, this study experimentally examined the effects of the three types of environmental knowledge on behavior, specifically the intention to consume animal products and actual consumption behavior (i.e., sandwich topping choice and chocolate choice). We focused on the consumption of animal products as a high-impact behavior to mitigate climate change (Lacroix, 2018; Wynes & Nicholas, 2017). Animal-based foods already account for 57% of global food-related greenhouse gas emissions (Xu et al., 2021). If current dietary pattern persist, food consumption alone could add about 1 °C to global warming by 2100 (Ivanovich et al., 2023). Consequently, reducing or avoiding animal products is among the most effective actions to lower greenhouse gas emissions on individual level and constitutes a critical target for interventions (Lacroix, 2018; Scarborough et al., 2023; Springman et al., 2018; Wynes & Nicholas, 2017). For analytical simplicity and to enhance interpretability for readers, the present study focused on CO_2 emissions resulting from the consumption of animal products. Thus, participants' intention to consume animal products was operationalized as a CO_2 emission score (in kg) for animal products, providing a standardized alternative to traditional intention measures for quantifying the environmental impact of their intended consumption. For example, on traditional intention scales, the same strong intention to reduce chicken consumption leads to different emission reductions for frequent chicken consumers than for those who eat it already rarely. In contrast, CO_2 emission scores enhance the reliability and comparability of consumption pattern (see Morren et al., 2021, and Seger et al., 2023, for similar approaches).

Recognizing the interconnectedness of the knowledge types (Liefländer et al., 2015), we compared conditions in which participants were presented with learning material containing (1) *system knowledge* alone, or (2) *action-related knowledge* and *system knowledge*, or (3) *effectiveness knowledge* and *system* and *action-related knowledge*. By presenting specific environmental knowledge content, we manipulated participants' objective knowledge levels, thus avoiding approaches in which environmental knowledge was assessed based on participants' subjective estimations of their knowledge (Geiger et al., 2019). The following examples illustrate the operationalization of the knowledge types within the learning texts: system knowledge included facts such as primary greenhouse gas emissions from livestock production originate from for example deforestation, methane from livestock digestion and manure, or excessive fertilizer usage (Ivanovich et al., 2023; Scarborough et al., 2023; Schlatzer, 2011); action-related knowledge focused on strategies for emission reduction in the livestock production (Scarborough et al., 2023; Springman et al., 2018); effectiveness knowledge conveyed that a vegan diet generates significantly fewer greenhouse gas emissions than a vegetarian diet, which, in turn, emits less than an omnivore diet (Scarborough et al., 2023; Xu et al., 2021).

In line with the theoretical knowledge structure, participants in our study who learned system, action-related and effectiveness knowledge were presented with three texts, each containing the specific knowledge type facts. To maintain a consistent learning time, participants of all conditions were presented with three texts with differing contents depending on the assigned condition. To control for overall knowledge quantity, we introduced a 'high system knowledge' condition in which participants read three texts containing only system knowledge. This ensured that any differences observed between the knowledge conditions were due to the types of knowledge rather than the total amount of knowledge. A second control condition included environment-unrelated knowledge only (i.e., texts about the impact of physical activities on cognitive abilities). Further, we assessed affinity for animal products as possible covariate, which refers to a positive, largely emotion-driven attitude toward animal-based foods, which can directly influence purchasing decisions independently of objective product evaluations (de Boer & Schösler, 2016; Oberecker et al., 2008; see also meat attachment, Graça et al., 2015). Therefore, participants' affinity for animal products may shape their consumption choices regardless of what they learned about the foods' impact.

1.2.1 Expected Effects of the Three Environmental Knowledge Types

We examined the effects of the environmental knowledge types on individual's behavior intention as key predictor of pro-environmental behavior (Bamberg & Möser, 2007; Hines et al., 1987; Klöckner, 2013). To capture actual consumption behavior, we included participants' choice of a voucher for a sandwich topping of a local diner (i.e., vegan vs. cheese vs. chicken vs. beef topping) and a choice of a chocolate bar (i.e., vegan vs. milk chocolate). Thus, while intentions primarily reflect cognitive and motivational processes, the translation of pro-environmental intentions into behavior is often constrained by additional factors, including individual factors (e.g., habits), situational constraints (e.g., limited access to sustainable alternatives), and social environmental factors (e.g., social norms; Hu et al., 2025; Klöckner, 2013; van Valkengoed et al., 2022). It is crucial to examine whether certain forms of environmental knowledge are more effective than others in overcoming these factors or constraints, and therefore focus on both, intentions and actual behavior. Moreover, considering actual behavior as dependent variable enhances the applicability and generalizability of the research, allowing for a more accurate understanding of the impact of environmental knowledge on behavior in practical contexts (see Lange et al., 2023).

In line with the framework of the multidimensional structure of environmental knowledge (Frick et al., 2004; Kaiser & Fuhrer, 2003; Kaiser et al., 2008; Roczen et al., 2014), we hypothesized that the effect of environmental knowledge differs across knowledge types, both with respect to intended consumption of animal products (operationalized by CO_2 emission scores in kg; H1) and to actual consumption behavior (i.e., the probability of choosing the vegan product; H2).

Empirical evidence suggests that system knowledge does not directly influence pro-environmental behavior (Frick et al., 2004), but affects attitudinal processes that shape intentions (Kaiser et al., 2008). Due to the complexity of environmental problems, system knowledge on its own might be simplified by individuals, leading to an underestimation of the problems, or, can evoke feelings of helplessness, triggering cognitive defense mechanisms such as denial, resignation, or blame shifting (Kollmuss and Agyeman, 2002). Consequently, individuals often fail to translate pro-environmental intentions into actual behavior (Hu et al., 2025). Accordingly, we assume that in the system knowledge only (SYS) condition, the intention to consume animal products (i.e., the CO_2 emission score in kg) is lower than in the environment-unrelated knowledge (ENV_UNR) condition (H1a). At the same time, no transfer effects were expected for the environment-related behavior due to the aforementioned simplification processes assumed. Thus, no difference concerning individuals' actual consumption behavior was expected in the current experiment between ENV_UNR and SYS (H2a).

By providing action-related knowledge in addition to system knowledge, individuals receive concrete and actionable behavioral guidance, involving them personally. Following the Theory of Planned Behavior (Ajzen, 1991), this knowledge type can change individuals' perceived behavioral control, which is the reported ability to perform a specific behavior (Ajzen, 1991) and influences individuals' behavioral intention directly (e.g., Bamberg & Möser, 2007; Frick et al., 2004; Neubig et al., 2020). Therefore, we hypothesized that the intended consumption of animal products (i.e., the CO_2 emission score in kg) is lower in the system and action-related knowledge (SYS+ACT) condition compared to ENV_UNR and SYS (H1b). Similarly, the probability of choosing a vegan product was expected to be higher in SYS+ACT compared to ENV_UNR and SYS (H2b) because the content of action-related knowledge provides concrete and practicable behavioral actions, stimulating behavioral change (e.g., Ajzen, 1991; Liobikienė & Poškus, 2019; Neubig et al., 2020).

Individuals' perceived behavioral control should be triggered even more by effectiveness knowledge: As effectiveness knowledge informs individuals about the impact of proposed actions, it highlights the individual contribution to mitigate climate change (Kaiser & Fuhrer, 2003; Liefländer et al., 2015). Information on the effectiveness of behavior options should encourage individuals to behave pro-environmentally by giving them the feeling to achieve a change by means of their behavioral change (Frick et al., 2004; Kaiser et al., 2008). We hypothesized that the intended consumption of animal products (i.e., the CO_2 emission score in kg) should be the lowest in the system, action-related, and effectiveness knowledge (SYS+ACT+EFF) condition compared to ENV_UNR, SYS, or SYS+ACT (H1c). Analogously, the highest probability for choosing a vegan product was expected for SYS+ACT+EFF compared to ENV_UNR, SYS, and SYS+ACT (H2c). Thus, effectiveness knowledge should motivate individuals to promote pro-environmental actions by empowering them to believe in their ability to achieve environmental change through behavioral change (Frick et al., 2004; Kaiser et al., 2008).

1.2.2 Quantity of knowledge as additional control condition

Since participants who learned effectiveness knowledge facts also learned system and action-related knowledge facts, possible differential effects between the knowledge conditions could be attributed to the total quantity of environmental knowledge rather than the specific quality of knowledge gained in each condition. To address this, we included an additional control condition, referred to as the 'high system knowledge' (SYS+SYS+SYS) condition. If the types of environmental knowledge are decisive for pro-environmental behavior and intentions—and not the quantity of system knowledge—no differences were expected in the pattern of results between SYS and SYS+SYS+SYS regarding both, behavioral intentions (H3) and actual behaviors (H4). In particular, we expected a lower intention to consume animal products (i.e., a lower CO_2 emission score in kg) in SYS+SYS+SYS compared to ENV_UNR (H3a, cf. H1a), but a higher intention (i.e., higher CO_2 emission score) compared to SYS+ACT (H3b, cf. H1b) and SYS+ACT+EFF (H3c, cf. H1c). For actual consumption behavior, we expected no differences in participants' choices between SYS+SYS+SYS and ENV_UNR

(H4a, cf. H4a). We expected participants in the SYS+SYS+SYS to opt less frequently for the vegan than participants in SYS+ACT (H4b, cf. H2b) and SYS+ACT+EFF (H4c, cf. H2c).

2 Methods

The study was preregistered at https://doi.org/10.17605/OSF.IO/9YHVK.

2.1 Design

The experiment followed a one-factorial between-subjects design with the factor *knowledge type*: (1) system knowledge (SYS), (2) system and action-related knowledge (SYS+ACT), (3) system, action-related and effectiveness knowledge (SYS+ACT+EFF), (4) environment-unrelated knowledge (ENV_UNR) as control condition 1, and (5) high system knowledge (SYS+SYS+SYS) as control condition 2. The dependent variables were assessed immediately after the intervention: (1) participants' self-reported *intention to consume animal products* within the upcoming seven days, (2) their *choice of a sandwich topping* (i.e., voucher for a sandwich with either vegan, chicken, cheese, or beef topping), and (3) their *chocolate choice* (i.e., vegan or milk chocolate). The choice of the vegan alternative served as indicator of pro-environmental behavior. The choice of the sandwich and the chocolate served additionally as compensation for participation.[2]

As baseline for dietary behavior, we assessed participants' pre-interventional consumption of animal products by a self-report questionnaire, which was also used after the intervention to measure their intention to consume animal products. Both variables were operationalized by CO_2 emission scores (in kg) for animal products.[3] As possible covariate, we measured participants' affinity for animal products.

2.2 Sample

A total of 322 students of the University of Kassel, Germany, took part in this study, of which 18 were excluded because of reporting a vegan diet. Participants were recruited via the online study platform of the Institute of Psychology, announcements in lectures and seminars, posters on campus, and personal contact. The final sample (N = 304) included 89 males, 211 females, 4 diverse, aged between 18 and 49 years (M = 23.31, SD = 5.32). All participants received a voucher

[2] The selection of these products for assessing actual consumption behavior was guided by practical and methodological considerations. We aimed to choose incentives that were attractive to participants, feasible to provide, and suitable as dependent variables. Sandwiches were selected because they offered a variety of options (e.g., different types of meat, dairy-based, and vegan), and the cooperating local sandwich store was able to implement the voucher procedure required for our study. Chocolate was chosen as a sweet counterpart because it could be easily distributed in the office and taken home immediately by participants.

[3] We further assessed the *self-reported actual dietary behavior* for the last 7 days four weeks after the intervention. Due to participants' drop out (10.86%), we dropped analyses of this variable.

for a sandwich of a local diner and a chocolate as part of the experiment, but covered as incentive. Psychology students (*n* = 143) could additionally receive course credits for participation.

Participants were randomly assigned to the conditions (SYS: *n* = 62; SYS+ACT: *n* = 61; SYS+ACT+EFF: *n* = 63; ENV_UNR: *n* = 61; SYS+SYS+SYS: *n* = 57).

Sample sizes for the sandwich and chocolate choice differed due to different exclusion criteria (e.g., lactose intolerance) and drop out of participants during data collection process (for a detailed description of data exclusion see supplemental material Appendix SC). The final sample for sandwich topping was *N* = 250 (SYS: *n* = 55, SYS+ACT: *n* = 50, SYS+ACT+EFF: *n* = 51, ENV_UNR: *n* = 48, SYS+SYS+SYS: *n* = 46) and for chocolate choice was *N* = 189 (SYS: *n* = 41, SYS+ACT: *n* = 34, SYS+ACT+EFF: *n* = 38, ENV_UNR: *n* = 38, SYS+SYS+SYS: *n* = 38).

2.3 Procedure and material

The experiment was framed as a study on the effects of physical activity and diet. The first part was a computer-based laboratory session, using Sosci Survey (Leiner, 2019), which participants completed on average in *M* = 45.9 min (*SD* = 9.6). Measures for actual consumption behavior were thereafter assessed in the main researcher's office. After completion of the entire study, participants were debriefed.

2.3.1 Pre-intervention measures

The experiment started by assessing demographic variables, including age, gender, German-language skills and study subject. For exclusion criteria, we assessed participants' general dietary behavior and their avoidance of specific food products due to allergies, intolerances, religious, or other reasons.

The assessment of the general consumption of animal products followed. Participants were asked how many portions of specific animal products they are consuming in a regular week (i.e., consumption of animal products before the intervention). These details were requested separately for breakfast, lunch, snack, and dinner to facilitate the estimations for participants. After an example, participants were presented with a list of different ingredients. Behind each ingredient, they could indicate how many portions of it they typically consume. For each product, we indicated what one portion was meant to be in gram or liter. For example, for milk, one portion was equated with approx. 250 ml or a glass. For each animal product, we calculated a sum score over breakfast, lunch, snack, and dinner answers. To generate an objective measure of the impact of the consumption of animal products on climate, each animal product sum score was than weighted with the corresponding CO_2 emissions (in kg) taken from goClimate.de (2023; see supplemental material Table SA1 for the emission values used). Subsequently, the resulting CO_2 emissions per animal product were summed up, resulting in a score for their consumption of animal products assessed before the intervention. To avoid priming on animal products, other products such as vegetables, fruit and cereals were also listed, but not further analyzed.

Afterwards, we measured the affinity for animal products with a 5-item scale, adapted from a larger German research project on sustainable dietary behavior (KERNiG; Schanz et al., 2020). On a 5-point scale ranging from 1 (I don't agree at all) to 5 (I totally agree), participants answered statements such as "Animal products belong to a proper meal," or "Dishes without animal products are bland and boring" (close English translation; see supplemental material Table SB1 for the entire scale). The responses were averaged resulting in a single score for each participant, with higher scores indicating a higher affinity for animal products. Scale reliability was good with Cronbach's $\alpha = 0.81$. To distract participants from the main focus of the study, participants were afterwards asked about their general physical activity. These items served as distractors only.

To avoid potential testing effects that could influence participants' environmental knowledge and affect the outcomes, we chose not to conduct a pre-intervention knowledge test. Instead, participants were randomly assigned to one of five conditions to promote balanced group distribution in our study design (see below).

2.3.2 Intervention

The intervention followed, in which participants were randomly assigned to one of the five knowledge conditions and, according to these, presented with three different informative texts (see below). Given the theoretical structure of environmental knowledge types, the order of system, action-related, and effectiveness knowledge texts (in both, the environment and the environment-unrelated knowledge texts) was not random, but in this specific order. The content structure of the environment-unrelated texts about the effects of physical activity on cognitive abilities was similar to that of the environmental knowledge types (i.e., system knowledge, action-related knowledge, and effectiveness knowledge). All texts compiled real facts from different, mainly scientific and governmental sources[4].

In the SYS condition, the first text addressed *system knowledge* (1156 words). It discussed the effects of global warming, including the increase in greenhouse gas emissions, the role of the agriculture and food industry in contributing to climate change, the impacts on the environment, such as the melting of permafrost and changes in ecosystems and species distribution (e.g., Nelles & Serrer, 2018; Schlatzer, 2011; Umweltbundesamt, 2014). In order to keep the learning duration constant, participants were afterwards presented with two environment-unrelated texts. Thus, the second text comprised *environment-unrelated system knowledge* (1146 words) about the relationship of physical activity and cognitive functions. It discussed the global decrease in physical activity and explained how physical activity improves oxygen utilization, blood flow to the brain, and the production of neurotrophins (e.g., Hillman et al., 2005; Sofi et al., 2011). The third text comprised the *environment-unrelated action-related knowledge* (1071 words) that suggested aerobic exercises, active commuting, and office exercises as ways to incorporate physical activity into daily routines to mitigate age-related declines in physical and cognitive abilities (e.g., Chang et al., 2010; Hillman et al., 2005; Sofi et al., 2011).

[4] See https://doi.org/10.17605/OSF.IO/GN3TZ for the used material.

In the SYS+ACT condition, participants read the system knowledge text first (see earlier). Afterwards, they read the *action-related knowledge text* (1065 words). The text discussed strategies to reduce greenhouse gas emissions in the animal production sector, such as implementing sustainable land management practices, eliminating subsidies, or reducing meat consumption as potential approaches (e.g., Hirschfeld et al., 2008; Lithourgidis et al., 2011; Schlatzer, 2011; Umweltbundesamt, 2019). Finally, they read the environment-unrelated system knowledge text (see earlier).

In the SYS+ACT+EFF condition, participants read first the system knowledge text, then the action-related knowledge text (see earlier), and in the end the *effectiveness knowledge text* (1067 words). The text discussed measures to improve efficiency in animal production and increase carbon dioxide storage through improved land management. However, it suggests that reducing animal production or consumption is the most important measure to reduce greenhouse gas emissions in the livestock sector. The text also presented the emissions of various food items, emphasizing the higher emissions associated with animal products compared to plant-based alternatives (e.g., Schlatzer, 2011; Upfield Europe BV, n.d.; see also goClimate.de, 2023, for a similar current resource).

In the ENV_UNR condition, participants read first the environment-unrelated system knowledge text, followed by the environment-unrelated action-related knowledge condition (see earlier). Finally, they read the *environment-unrelated effectiveness knowledge text* (1089 words), which contained facts on the effectiveness of different physical activities on cognitive functions, such as regular aerobic exercise which enhances brain oxygenation (e.g., Chang et al., 2010; Hillman et al., 2005; Sofi et al., 2011).

In the SYS+SYS+SYS condition, participants started with the same system knowledge text presented to the other environmental knowledge conditions. Afterwards, they read a *second environment-related system knowledge text* (1079 words) extending the facts on ice melting reported in the first system knowledge text to the potential weakening of the Atlantic Meridional Overturning Circulation and impacts on freshwater resources (e.g., Nelles & Serrer, 2018). Then, participants read a *third environment-related system knowledge text* (1047 words) that discussed the conversion of natural habitats, such as forests, wetlands and peatlands, into agricultural and pastureland (e.g., Bundesministerium für Bildung und Forschung, 2017; Schlatzer, 2011).

After reading each text, participants answered five-single choice test questions on content of that text to ensure that they had acquired the corresponding knowledge. Corrective feedback was provided after each response, and incorrectly answered items were re-presented until recalled correctly. Only then were participants able to continue with the study. Participants took on average M = 1.22 (SD = 0.67) trials to answer each question.[5] This procedure was based on the effect of

[5] Participants in conditions with texts referring to more environmental knowledge content (e.g., SYS+SYS+SYS) completed more test questions on environmental knowledge content than those in conditions with less (e.g., SYS) or none (i.e., ENV_UNR). These test

retrieval practice, also known as the testing effect, to induce a high level of recall success and long-term retention of knowledge (Pyc & Rawson, 2009, 2012; for the use in learning environmental knowledge content, see Mundt et al., 2024). This approach addressed the critical issue of low or incorrect participant knowledge in previous studies of environmental knowledge types (e.g., Fremerey & Bogner, 2014; Frick et al., 2004).

2.3.3 Post-intervention measures

Immediately after the intervention, participants were asked to report their intention to consume animal products for the upcoming seven days, as we did for the consumption of animal products before the intervention, analogous to the assessment of their pre-intervention consumption. From these reports, we derived a CO_2 emissions score reflecting their intended dietary behavior. As in the previous assessment, these items were embedded within questions concerning intended physical activity.

After being thanked, participants were told to quietly leave the room and go to the main researcher's office at the end of the corridor to receive the voucher for a sandwich and a chocolate bar as part of their compensation. Participants received a small note with the directions that had to be handed over to the main researcher when they entered individually her office. On the slip of paper, the subject number was inconspicuously noted before, in order to link the sandwich and chocolate choices with the previous data. The presentation order of the vouchers and chocolate bars was counter-balanced between participants.

Regarding the sandwich vouchers, the main researcher told the participant that there were four different vouchers to choose of - each for a different sandwich of a local diner (i.e., vegan, cheese, chicken and beef). All four vouchers had the same design with different product names only. The vouchers were placed in a bookshelf two meters opposite of the researcher, with the order counterbalanced. To minimize feelings of observation, participants turned their backs to the researcher, with the desk in between. Once participants selected a voucher, the main researcher stamped and signed the voucher for validation. This process allowed the researcher to record the participants' choice along with their subject number when the participant left the room.

As for the chocolate choice, participants were invited to choose a chocolate bar out of two identical boxes that were placed in the shelf below the vouchers. To avoid branding effects, we did not present the chocolates themselves. The boxes were labelled "vegan 'milk' chocolate" and "milk chocolate" to avoid confusions with dark and bitter vegan chocolate. Additionally, participants were verbally informed that both chocolates were equally sweet.

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questions are therefore considered an integral part of the intervention rather than an independent variable that could explain our observed effects. To account for potential effects of processing time in text reading and test answering, we conducted exploratory analyses excluding extreme outliers in processing times. The results were consistent with those reported in the manuscript and did not change the overall interpretation. Full details of these analyses are available at https://doi.org/10.17605/OSF.IO/GN3TZ.

3 Results

For data processing and analyses, we used R (Version 4.5.1; R Core Team, 2021). Data and R script are available open access at https://doi.org/10.17605/OSF.IO/GN3TZ. Unless otherwise specified, significance level was set at .05. In case of pairwise comparisons, *p*-values were adjusted using the false discovery rate (Benjamini & Hochberg, 1995). For statistical analysis, the continuous variables affinity for animal products, consumption of animal products before the intervention, and intention to consume animal products were centered at their respective means. See Table 1 for an overview of hypotheses and empirical support.

3.1 Effects of knowledge types on the intention to consume animal products (H1)

Figure 1 depicts the mean values and confidence levels for the CO_2-emission score referring to participants' intention to consume animal products after the intervention for each knowledge condition. See Table A1 for descriptive results for consumption of animal products before the intervention, intention to consume animal products after the intervention and the affinity for animal products. Before the intervention, participants in the different conditions did not differ in their consumption of animal products as an ANOVA revealed, $F(4, 299) = 0.79$, $p = .531$.

To test whether the intention to consume animal products differs depending on the environmental knowledge type (H1), we conducted a multiple linear regression analysis with the intention to consume animal products after the intervention as criterion and the dummy-coded knowledge types as predictor.[6] ENV_UNR served as comparison group in the dummy-coding of knowledge type. The consumption of animal products before the intervention, the affinity for animal products, and their interaction were included as additional predictors to consider that the effect of pre-intervention consumption depends on affinity (e.g., Graça et al., 2015).

As depicted in Table 2, the intention to consume animal products assessed before the intervention, the affinity for animal products and their interaction predicted the intention to consume animal products. Concerning the knowledge conditions, we found a lower intention to consume animal products (i.e., lower CO_2 emission scores) for SYS+ACT+EFF and SYS+SYS+SYS compared to ENV_UNR. The adjusted Cohen's *d* was 0.52, 95% *CI* [0.16, 0.87] for ENV_UNR vs. SYS+ACT+EFF and 0.59, 95% *CI* [0.23, 0.85] for ENV_UNR vs. SYS+SYS+SYS. Contrast analyses revealed no further statistical differences between the knowledge conditions (see Table 3).

[6] We initially planned to use a repeated-measures ANCOVA to analyze the intended animal product consumption, however a multiple linear regression analysis resulted in being more suitable for our data because it does not require 'pre-intervention animal production' and 'intended animal product consumption' to be commensurable.

Table 1

Overview of Hypotheses and Their Empirical Support According to Regression Analyses

Hypotheses			Corroboration
Related to the intention to consume animal products	Differing Effects of the Environmental Knowledge Types		
	H1a:	The intended CO_2 emission score for animal products for SYS is lower compared to ENV_UNR.	X
	H1b:	The intended CO_2 emission score for animal products for SYS+ACT is lower compared to ENV_UNR	X
		and compared to SYS.	X
	H1c:	The intended CO_2 emission score for animal products for SYS+ACT+EFF is lower compared to ENV_UNR,	✓
		and compared to SYS,	X
		or compared to SYS+ACT.	X
	Quantity vs. Quality of Knowledge Types[a]		
	H3a:	The intended CO_2 emission score for animal products for SYS+SYS+SYS is lower compared to ENV_UNR	✓ [b]
	H3b:	The intended CO_2 emission score for animal products for SYS+SYS+SYS is higher compared to SYS+ACT	X
	H3c:	The intended CO_2 emission score for animal products for SYS+SYS+SYS is higher compared to SYS+ACT+EFF	X
Related to actual consumption behavior	Differing Effects of the Environmental Knowledge Types		
	H2a:	The probability of choosing a vegan product does not differ between ENV_UNR and SYS.	✓
	H2b:	The probability of choosing a vegan product in SYS+ACT is higher compared to ENV_UNR	X
		and compared to SYS.	X
	H2c:	The probability of choosing a vegan product in SYS+ACT+EFF is higher compared to ENV_UNR,	X
		and compared to SYS,	X
		or compared to SYS+ACT.	X
	Quantity vs. Quality of Knowledge Types[a]		
	H4a:	The probability of choosing a vegan product does not differ between ENV_UNR and SYS+SYS+SYS.	✓ [c]
	H4b:	The probability of choosing a vegan product in SYS+SYS+SYS is lower compared to SYS+ACT.	X
	H4c:	The probability of choosing a vegan product in SYS+SYS+SYS is lower compared to SYS+ACT+EFF.	X

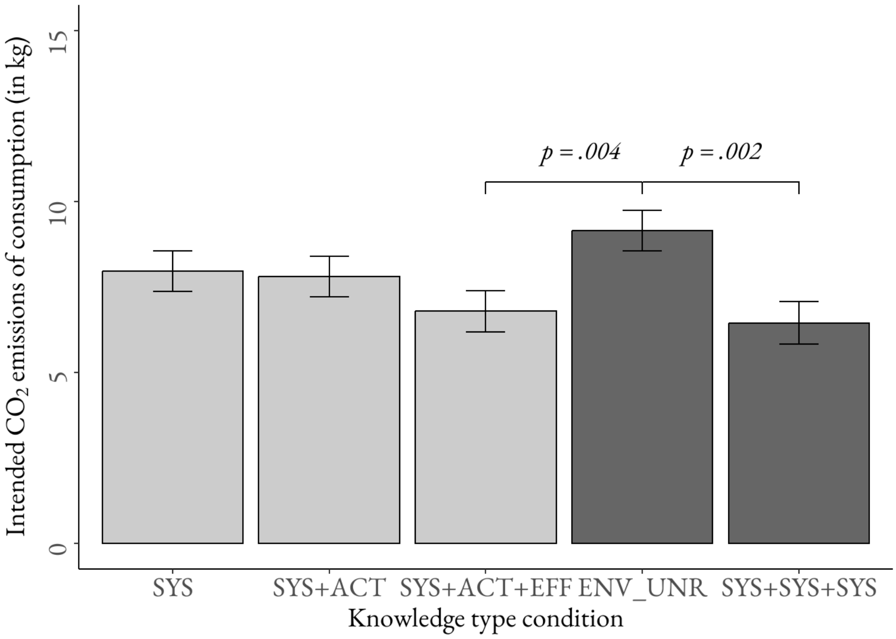
Note. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, ENV_UNR = environment-unrelated knowledge, SYS+SYS+SYS = high system knowledge.

[a] These hypotheses build on the assumption that the type (quality) rather than the amount (quantity) of environmental knowledge determine the expected effect. Therefore, the expected pattern for SYS+SYS+SYS is the same as for SYS (cf. H1 and H2).

[b] Moderate evidence for equality of ENV_UNR vs. SYS and ENV_UNR vs. SYS+SYS+SYS from a Bayesian confirmatory hypothesis test. [c] Inconclusive (for vegan vs. cheese topping choice) and strong (for vegan vs. meat topping choice, and vegan vs. milk chocolate choice) evidence for equality of ENV_UNR vs. SYS and ENV_UNR vs. SYS+SYS+SYS from Bayesian confirmatory hypothesis tests.

Figure 1

Estimated Marginal Means (EMMs) of the Intention to Consume Animal Products (Operationalized by CO_2 Emission Score in kg) *After the Intervention for Each Knowledge Condition*



Note. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, ENV_UNR = environment-unrelated knowledge, SYS+SYS+SYS = high system knowledge. Adjustment of *p*-values with False Discovery Rate. Error bars represent ± 1 *SE* of the *EMMs*.

The results were not in line with H1a, as the intention to consume animal products was not lower for SYS compared to ENV_UNR. Similarly, H1b was not supported, because the intended consumption of animal products was not lower in SYS+ACT than in SYS. H1c was corroborated regarding a lower intention to consume animal products in SYS+ACT+EFF compared to ENV_UNR, but not compared to the other conditions.

Table 2

Results of Multiple Regression for the Intention to Consume Animal Products With Estimated Coefficients (b), Standard Errors (SE), Standardized Estimated Coefficients (β), t- and p-Values

Predictors	*b*	*95% CI*		*SE*	β	*t*	*p*
		lower	*upper*				
Intercept	1.09	-0.08	2.26	0.59	0.13	1.84	.067
SYS[a]	-1.19	-2.81	0.44	0.83	-0.15	-1.44	.152
SYS+ACT[a]	-1.34	-2.97	0.29	0.83	-0.17	-1.62	.106
SYS+ACT +EFF[a]	-2.36	-3.98	-0.74	0.82	-0.29	-2.86	.004
SYS+SYS+SYS[a]	-2.70	-4.37	-1.03	0.85	-0.33	-3.19	.002
Pre_ consumption	0.55	0.49	0.61	0.03	0.71	18.88	< .001
Affinity	1.48	0.84	2.13	0.33	0.16	4.54	< .001
Pre_consumption × affinity	0.10	0.05	0.16	0.03	0.12	3.55	< .001

Note. $N = 304$. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, SYS+SYS+SYS = high system knowledge, Pre_consumption = consumption of animal products before the intervention, Affinity = affinity for animal products. *CI* = confidence interval for estimated coefficient *b*. Consumption of animal products before the intervention, intention to consume animal products, and affinity for animal products were centered at their respective means. $F(296) = 94.25$, $p < .001$. $R^2 = 0.69$, $R_{adj}^2 = 0.68$.
[a] dummy variables with ENV_UNR (environment-unrelated knowledge) as comparison group.

Table 3

Contrast analyses for multiple regressions predicting the Intention to Consume Animal Products with Difference of Estimated Marginal Means (ΔEMM), Standard Error (SE), t- and p-Values (Unadjusted [p] and Adjusted With False Discovery Rate [p – fdr]), and Effect Sizes (Adj. Cohen's d)

Contrast (I-J)		*ΔEMM*	*SE*	*t*	*p*	*p-fdr*	*Adj. d*	*95% CI*	
I	J							lower	upper
SYS	SYS+ACT	0.16	0.83	0.19	.850	.850	0.03	-0.32	0.39
SYS	SYS+ACT+EFF	1.17	0.82	1.43	.154	.308	0.26	-0.10	0.61
SYS+ACT	SYS+ACT+EFF	1.02	0.83	1.23	.220	.330	0.22	-0.13	0.58
SYS	SYS+SYS+SYS	1.51	0.84	1.80	.074	.308	0.33	-0.03	0.69
SYS+ACT	SYS+SYS+SYS	1.36	0.85	1.60	.110	.308	0.30	-0.07	0.66
SYS+ACT+EFF	SYS+SYS+SYS	0.34	0.84	0.41	.683	.819	0.07	-0.29	0.44

Note. $df = 296$. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, SYS+SYS+SYS = high system knowledge. *Adj. d* = adjusted Cohen's *d*: difference between estimated marginal means divided by the model residual *SD*. *CI* = confidence interval for *adj. d*.

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3.2 Effects of knowledge types on actual consumption behavior (H2)

As shown by the descriptive results depicted in Table A1, only few participants chose the beef topping. Therefore, we coded the chicken and beef toppings together as "meat" category, resulting in the codings: 0 = vegan topping, 1 = cheese, 2 = meat for the DV sandwich topping.

To test H2 that sandwich topping choice differs depending on the environmental knowledge type, we conducted two binomial logistic regression analyses with the criterion topping choice[7] (Model 1: vegan = 0 and cheese = 1; Model 2: vegan = 0 and meat = 1). The dummy-coded knowledge type was included as predictor and the affinity for animal products as covariate. ENV_UNR served as comparison group. See Table 4 for results of the two binomial logistic regressions. Only the affinity for animal products predicted the sandwich topping choice. The environmental knowledge conditions did not yield any difference in sandwich topping choice (see also Table 5 for contrast analyses).[8]

Similarly, for chocolate choice, we conducted a binomial logistic regression analysis with the criterion chocolate choice (vegan = 0, milk = 1) and the dummy-coded knowledge type as predictor and the affinity for animal products as covariate.

ENV_UNR served as comparison group (see Table A1 for descriptive results of chocolate choices and Table 6 for results of the binomial logistic regression analysis). Only the affinity for animal products predicted the chocolate choice. The environmental knowledge conditions did not show any difference in chocolate choice (see also Table 5 for contrast analyses).

Consistent with H2a, both, sandwich topping choice and chocolate choice were not significantly different between ENV_UNR and SYS. To directly test the assumed equality between ENV_UNR and SYS, we further conducted a Bayesian confirmatory hypothesis test with the BF.lm function of the R package *BFpack* (Mulder et al., 2021).[9] The analysis was based on the regression coefficients using generalized adjusted fractional Bayes factors. For vegan vs. cheese topping choice, the Bayes factor indicated strong evidence for the equality between ENV_UNR and SYS, BF_{01} = 13.25. Evidence for equality in vegan vs. meat topping choice was

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[7] We preregistered a multivariate logistic regression. Due to software limitations, the intended contrast analyses were not possible for a multivariate logistic regression. Therefore, we estimated two binomial logistical regressions instead. Note that these approaches are equivalent and model coefficients did not differ between both data-analytic approaches.

[8] Exploratively, we analyzed solely vegetarian participants, as they could choose only between vegan and cheese toppings. This subgroup analysis on sandwich topping choice (*n* = 49) indicated significant differences between ENV_UNR and SYS+ACT (*OR* = 0.06), and ENV_UNR and SYS+SYS+SYS (*OR* = 0.04), but not among the other conditions. No differences were found for intention (n = 60) or chocolate choice (n = 35). Given the small sample sizes, results should be interpreted with caution. For further details and additional exploratory analyses see https://doi.org/10.17605/OSF.IO/GN3TZ.

[9] This analytic approach was not pre-registered. We believe that adding this statistical approach adds important information to our results, because Bayesian statistics can directly quantify the evidence in favor of the null hypothesis of equality (cf. Mulder et al., 2021).

also strong, BF_{01} = 12.69. For chocolate choice, evidence for equality between ENV_UNR and SYS was moderate, BF_{01} = 7.59.

Contrary to H2b, choosing the vegan product was not more likely in SYS+ACT compared to ENV_UNR and SYS, neither in sandwich topping choice nor chocolate choice. Similarly, choosing the vegan product was not more likely in SYS+ACT+EFF compared to ENV_UNR, SYS, and SYS+ACT, not supporting H2c.

Table 4

Results of the two Binomial Logistic Regressions for Sandwich Topping Choice as Criterion, with Estimated Coefficients (b), Standard Errors (SE), z- and p-Values, and Odds Ratios (OR)

Knowledge condition		*b*	*SE*	*z*	*p*	*OR*	*95% CI*	
							lower	*upper*
Model 1	Intercept	0.47	0.36	1.31	.190	1.60	0.79	3.25
	SYS[a]	0.06	0.50	0.12	.905	1.06	0.40	2.84
	SYS+ACT[a]	-0.84	0.49	-1.71	.087	0.43	0.16	1.13
	SYS+ACT+EFF[a]	-0.38	0.49	-0.78	.435	0.68	0.26	1.78
	SYS+SYS+SYS[a]	-0.87	0.53	-1.64	.100	0.42	0.15	1.18
	Affinity for animal products[b]	0.68	0.20	3.43	< .001	1.98	1.34	2.91
Model 2	Intercept	-0.12	0.43	-0.29	.775	0.88	0.38	2.07
	SYS[a]	0.07	0.61	0.11	.910	1.07	0.32	3.57
	SYS+ACT[a]	-0.87	0.62	-1.40	.161	0.42	0.12	1.42
	SYS+ACT+EFF[a]	-0.24	0.59	-0.40	.689	0.79	0.25	2.53
	SYS+SYS+SYS[a]	-0.04	0.59	-0.07	.947	0.96	0.30	3.08
	Affinity for animal products[b]	1.57	0.27	5.85	< .001	4.79	2.83	8.11

Note. N = 250. Model 1 = vegan vs. cheese (with higher values signifying more choices for cheese toppings); Model 2 = vegan vs. meat (with higher values signifying more choices for meat toppings). SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, SYS+SYS+SYS = high system knowledge. *CI* = confidence level for the odds ratio (*OR*).
Model comparison of Model 1 with null model: $\chi^2(5) = 19.21, p = .002$; AIC = 239.46
Model comparison of Model 2 with null model $\chi^2(5) = 56.07, p < .001$; AIC = 179.67
[a] dummy variables with ENV_UNR (environment-unrelated knowledge) as comparison group. [b] centered at the mean.

Table 5

Contrast Analyses for Binomial Logistic Regressions Predicting Sandwich Topping Choice and Chocolate Choice with Odds Ratio (OR), Standard Error (SE), z- and p-Values (Unadjusted and Adjusted With False Discovery Rate).

Contrast (I-J)		Sandwich Topping Choice								Chocolate Choice			
		Model 1 (vegan vs. cheese)				Model 2 (vegan vs. meat)							
		OR	*SE*	*z*	*p*	*OR*	*SE*	*z*	*p*	*OR*	*SE*	*z*	*p*
I	J	95% *CI [LL, UL]*			(FDR)	95% *CI [LL, UL]*			(FDR)	95% *CI [LL, UL]*			(FDR)
SYS	SYS+ACT	2.47 [0.95, 6.45]	1.21	1.85	.065 (.474)	2.57 [0.76, 8.69]	1.60	1.52	.129 (.507)	1.34 [0.51, 3.50]	0.66	0.59	.554 (.893)
SYS	SYS+ACT+EFF	1.58 [0.60, 4.07]	0.76	0.90	.367 (.551)	1.36 [0.42, 4.36]	0.81	0.52	.606 (.808)	1.25 [0.50, 3.19]	0.60	0.47	.642 (.893)
SYS+ACT	SYS+ACT+EFF	0.63 [0.25, 1.61]	0.30	-0.96	.336 (.551)	0.53 [0.16, 1.73]	0.32	-1.05	.293 (.551)	0.94 [0.35, 2.50]	0.47	-0.14	.893 (.893)
SYS	SYS+SYS+SYS	2.54 [0.90, 7.17]	1.35	1.76	.079 (.474)	1.12 [0.35, 3.59]	0.67	0.18	.855 (.933)	1.13 [0.44, 2.86]	0.54	0.25	.805 (.893)
SYS+ACT	SYS+SYS+SYS	1.03 [0.37, 2.84]	0.53	0.05	.958 (.958)	0.43 [0.13, 1.43]	0.26	-1.37	.169 (.507)	0.84 [0.32, 2.24]	0.42	-0.35	.729 (.893)
SYS+ACT+EFF	SYS+SYS+SYS	1.63 [0.60, 4.52]	0.85	0.94	.346 (.551)	0.82 [0.27, 2.53]	0.47	-0.34	.731 (.877)	0.90 [0.35, 2.33]	0.44	-0.22	.829 (.893)

Note. *N* (Sandwich Topping Choice) = 250, *N* (Chocolate Choice) = 189. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, SYS+SYS+SYS = high system knowledge. *CI* = confidence interval for the odds ratio (*OR*), *LL* = lower limit, *UL* = upper limit. FDR = adjusted *p*-value with False Discovery Rate.

Table 6

Results of the Binomial Regression Model Predicting Chocolate Choice as Criterion, with Estimated Coefficients (b), Standard Errors (SE), z- and p-Values, and Odds Ratios (OR)

Predictor	*b*	*SE*	*z*	*p*	*OR*	*95% CI*	
						lower	*upper*
Intercept	0.36	0.34	1.05	.293	1.44	0.73	2.82
SYS [a]	-0.52	0.48	-1.09	.276	0.59	0.23	1.52
SYS+ACT [a]	-0.81	0.50	-1.62	.105	0.44	0.17	1.19
SYS+ACT +EFF [a]	-0.75	0.49	-1.54	.124	0.47	0.18	1.23
SYS + SYS+ SYS [a]	-0.64	0.49	-1.32	.188	0.53	0.20	1.37
Affinity for animal products[b]	0.670	0.17	3.85	< .001	1.95	1.39	2.74

Note. *N* = 189. SYS = system knowledge, SYS+ACT = system- and action-related knowledge, SYS+ACT+EFF = system, action-related, and effectiveness knowledge, SYS+SYS+SYS = high system knowledge. *CI* = confidence interval for the odds ratio (*OR*). Chocolate Choice coded with 0 = vegan, 1 = milk. Model comparison with null model: $\chi^2(5) = 19.85$, $p = 0.001$; $AIC = 253.52$
[a] dummy variables with ENV_UNR (environment-unrelated knowledge) as comparison group. [b] centered at the mean.

3.3 Quantity vs. type of environmental knowledge (H3, H4)

We expected that the quality of knowledge is relevant for intention change, not the quantity. Accordingly, we expected no difference in the pattern of results between SYS and SYS+SYS+SYS regarding both, behavioral intentions (operationalized by CO_2 emission scores in kg; H3) and actual behavior (i.e., choosing the environmentally friendly option in sandwich topping choice and chocolate choice; H4).

With respect to H3, the multiple linear regression analysis indicated a lower intention to consume animal products for SYS+SYS+SYS compared to ENV_UNR, corroborating H3a. However, this result did not align with the pattern observed for SYS, as SYS and ENV_UNR did not differ significantly (see Table 1).

Results were consistent with those for SYS regarding the non-significant differences between SYS+SYS+SYS and SYS+ACT, as well as SYS+SYS+SYS and SYS+ACT+EFF. Nonetheless, these results did not support H3b and H3c, respectively. SYS and SYS+SYS+SYS did not differ significantly from each other in the intention to consume animal products (see Table 2).

In order to confirm the equality hypothesis H3, we further calculated a Bayesian confirmatory hypothesis test. The analysis tested whether the difference of the intention to consume animal products between ENV_UNR and SYS was equal to the difference between ENV_UNR and SYS+SYS+SYS. The Bayes factor indicated moderate evidence for the equality, $BF_{01} = 4.27$.

With respect to H4, binomial regression analyses indicated that SYS and SYS+SYS+SYS followed the same pattern of results for sandwich topping and chocolate choice (see Table 3 and Table 4). In line with H4a, SYS+SYS+SYS did not differ significantly from ENV_UNR. Bayesian confirmatory hypothesis tests provided moderate evidence for equality between ENV_UNR and SYS+SYS+SYS in vegan versus cheese topping choice, BF_{01} = 3.46, and strong evidence for equality in vegan vs. meat topping choice, BF_{01} = 12.74. For chocolate choice, evidence for equality between ENV_UNR and SYS+SYS+SYS was moderate, BF_{01} = 5.77. In contrast, H4b and H4c were not corroborated: SYS+SYS+SYS did not differ significantly from SYS+ACT and SYS+ACT+EFF, respectively.

For sandwich topping choice, we further calculated two Bayesian confirmatory hypothesis tests, analyzing in both cases whether the difference of the sandwich topping choice between ENV_UNR and SYS was equal to the difference between ENV_UNR and SYS+SYS+SYS.[9] For vegan versus cheese topping choice, the Bayes factor indicated inconclusive evidence for equality, BF_{01} = 2.84. For vegan versus meat topping choice, the Bayes factor indicated strong evidence for the equality, BF_{01} = 12.56.

For chocolate choice, a Bayesian confirmatory hypothesis test was calculated to analyze whether the difference of the chocolate choice between ENV_UNR and SYS was equal to the difference between ENV_UNR and SYS+SYS+SYS. The Bayes factor indicated strong evidence for the equality, BF_{01} = 13.34.

To sum up, there were no differences between the pattern of results found between SYS and SYS+SYS+SYS, despite of a lower intention to consume animal products in SYS+SYS+SYS compared to ENV_UNR, but no differences in intention between SYS and ENV_UNR. The results of the Bayesian confirmatory hypothesis tests indicate that SYS and SYS+SYS+SYS did not differently affect the intention to consume animal products, sandwich topping choice, or chocolate choice.

4 Discussion

The present experiment investigated the effect of different environmental knowledge types (i.e., system, action-related, and effectiveness knowledge) on participants' intention to consume animal products (operationalized by CO_2 emission scores in kg) and their actual consumption behavior (i.e., sandwich topping choice; chocolate choice). To our knowledge, this is the first experimental study on the effects of the three environmental knowledge types (Player et al., 2023).

Overall, imparting different types of environmental knowledge did not lead to differences in participants' consumption intentions or actual consumption behavior. However, participants who acquired more environmental knowledge (i.e., all three environmental knowledge types – SYS+ACT+EFF, or a high system knowledge amount – SYS+SYS+SYS) demonstrated stronger pro-environmental intentions than those who learned no environmental knowledge content (ENV_UNR), partially corroborating H1c and H3a. The positive impact on intentions was similar for both conditions, suggesting that quantity rather than the quality (in terms of the specific type of environment-related knowledge) plays a crucial role. Thus, changing intentions seems to require a certain amount of knowledge, as conditions with less than three units of environment-related knowledge showed no notable effects on participants' intentions, such as SYS and SYS+ACT compared to ENV_UNR.

Between the conditions imparting environmental knowledge (i.e., SYS, SYS+ACT, SYS+ACT+EFF, SYS+SYS+SYS), there were no significant differences in the intention to consume animal products, contrary to expectations from H1. Bayesian confirmatory hypothesis tests indicated that the pattern of results for SYS and SYS+SYS+SYS were comparable (cf. H3), challenging the earlier assumption that the quantity of environmental knowledge was the decisive factor in influencing the intention to consume animal products.

With regard to actual consumption behavior (i.e., sandwich topping and chocolate choice), there were no effects of the different knowledge types. Thus, neither the quantity nor the quality of environment-related knowledge increased participants' actual choice of vegan products, compared to environment-unrelated knowledge, which was not in line with H2 and H4. However, as predicted in H4a, there were no differences between SYS and ENV_UNR in vegan product choice. A summary of all hypotheses and their corroboration is provided in Table 1.

4.1 Reasons for conflicting results

Several factors may explain our conflicting results regarding the role of quantity versus quality of environmental knowledge.

4.1.1 Influence of learning material and social norm activation

The framing of our study about the impact of food and fitness with physical activity items and texts related to cognitive abilities may have stimulated participants' consideration of a healthy lifestyle, which includes a reduced meat consumption (Morren et al., 2021). It is possible that any effects of environmental knowledge were overwritten by activated social norms within the sample (Bamberg & Möser, 2007). To address this, our unrelated-environmental knowledge control group was designed to also activate the health-related social norm. This was done in order to ensure that any observed effects could be attributed to environmental knowledge rather than to social norm activation. The rationale was that, given all participants were exposed to the same social norm, any systematic effects of environmental knowledge should still emerge. However, the social norm favouring health and, consequently, a pro-environmental diet may have been so pronounced in our highly educated, young and mainly female sample (Alkazemi, 2019; Mensink et al., 2016; Salameh et al., 2014; Wardle et al., 2004) that it effectively masked the specific effects of the environmental knowledge types. This may provide also a rationale for the observed effects being smaller than anticipated and for potential differences between conditions (ENV_UNR vs. SYS, ENV_UNR vs. SYS+ACT, and across the environmental knowledge conditions) being too subtle to be detected given our sample size. In this context, the results of the Bayesian confirmatory hypothesis tests indicating evidence for equality between SYS and SYS+SYS+SYS must be interpreted with caution, as estimation precision also depends on sample size (Kruschke & Liddell, 2017). Nevertheless, our study provides a basis for conducting a priori sample size calculations for future experimental work.

4.1.2 Potential confounding in knowledge manipulation

Since our learning material focused exclusively on animal-based food consumption, this may have introduced a content-related confounding of knowledge effects. Knowledge about greenhouse gas emissions from animal livestock production (i.e., system knowledge) or the options for reducing these emissions (i.e., action-related knowledge) lead to the mitigation behavior of consuming little to no animal products, regardless of whether this knowledge was acquired in detail through the effectiveness knowledge condition. Therefore, the effectiveness knowledge text could function more as an additional prompt. Research on attitude–behavior consistency further suggests that knowledge must be relevant to the targeted behavior to produce meaningful change (Fabrigar et al., 2006; Sun et al., 2023). Even individuals with relatively low levels of knowledge (i.e., system knowledge only) can show strong attitude–behavior alignment when their knowledge is directly tied to behavioral goals (Fabrigar et al., 2006). This reasoning may help explain why not only the SYS+ACT+EFF condition but also the SYS+SYS+SYS condition showed lower intentions to consume animal products compared to ENV_UNR, even though the latter contained only system knowledge. However, both assumptions are challenged by the finding that SYS and SYS+ACT had no effect on intention and behaviors.

4.1.3 Content-Specific Influences and Order Effects

It is important to carefully consider whether certain content within the presented texts can account for the observed effects, given that the presentation order of the text was not randomized. It is possible that specific information provided in SYS+SYS+SYS and SYS+ACT+EFF have elicited a more pronounced sense of problem awareness or personal norms in participants compared to SYS and SYS+ACT. In addition, the observed effect on behavioral intention for SYS+SYS+SYS and SYS+ACT+EFF may be linked to both conditions presenting environmental knowledge immediately before measuring intention, potentially creating a nudging effect consistent with the recency effect (Lockton, 2012). In order to take this potential influencing factor into account, future replications should randomize the presentation of the knowledge types such that the system knowledge is not presented exclusively at the beginning.

4.1.4 Discrepancies between intentions and actual behavior

With regard to the differing results between participants' intentions to consume animal products with their actual behavior, the findings suggests that pro-environmental intentions are more easily influenced by information than actual behavior. This is in line with previous intervention studies on environmental knowledge, which show that simply providing information does not necessarily lead to behavioral changes (e.g., Abrahamse et al., 2005; Carrington et al., 2010; Goodwin et al., 2010; Hassan et al., 2016). There are several other factors necessary to make individuals' modify their behavior (e.g., Osbaldiston & Schott, 2012; Verplanken & Wood, 2006). For instance, sustainable dietary behavior is likely to be influenced by pro-environmental attitudes (Al-Taie et al., 2015; Krömker & Matthies, 2014) or concern with animal welfare (Thomas et al., 2019). It is important to note, however, that interpreting the comparison between behavioral intentions and actual behavior in our study requires caution. The relatively high dropout rate in the behavior measurements, partly because of concealing the importance of the visit to the researcher's office, affected the statistical power and therefore, the overall statistical validity of the study's conclusions. Future replications may use another approach to measure actual behavior which includes less effort for the participants to counteract drop out, for example participants could make product choices directly in the laboratory setting, and receive the corresponding products based on their choices on site.

4.2 Recommendations for future experiments

As it remains empirically unclear whether the proposed three types of environmental knowledge types can clearly be distinguished and whether they affect pro-environmental behavior in different ways, further research is necessary. Despite decades of research on this construct (e.g., Kaiser & Frick, 2002; Player et al., 2023), empirical evidence is lacking, especially from experimental studies. This gap is crucial to address, as these knowledge types are widely recommended despite their uncertain relevance (e.g., Arnold, 2020; Smederrevac-Lalic et al., 2020; Somerwill & When, 2022). Our study may serve as a reference point for future experimental work.

4.2.1 Quantity versus quality of environmental knowledge

One focus of research should be on examining whether the quantity or quality of environmental knowledge matters in shaping behavior-related variables. Similar to our study, conditions such as SYS+SYS+SYS and SYS+ACT+EFF should be compared to SYS and SYS+ACT conditions. However, to rule out recency-effects, the order of text presentation should be varied in future studies, so that environmental knowledge is also presented as the final text sequence, rather than exclusively at the beginning. Other interesting comparison groups could include a high amount of action-related knowledge only and a high amount of effectiveness knowledge only. If it is the quantity of knowledge that drives effects rather than its quality, then all conditions involving large amounts of environmental knowledge should produce measurable effects compared to conditions involving moderate amounts.

4.2.2 The interconnectedness of the environmental knowledge types

Another focus of future research should be on examining the interconnectedness of the environmental knowledge types. Specifically, our experimental design does not enable us to investigate whether system knowledge influences behavior through action and efficacy knowledge (Braun & Dierkes, 2019; Frick et al., 2004). There is already evidence for effects of effectiveness knowledge alone (Goldwert et al., 2025; Simon & Merten, 2024), although we cannot rule out that these effects may have been supported by participants' pre-existing system and action-related knowledge. It would therefore be valuable to experimentally test how participants' post-intervention knowledge and behavior-related variables differ when they learn only one type of knowledge, or a combination of two, or all three environmental knowledge types. At the level of knowledge retention, if system knowledge facilitates the acquisition of action-related and, in turn, effectiveness knowledge, then participants who learned these knowledge types together with system knowledge should perform better on the corresponding post-intervention knowledge tests. Specifically, participants should score higher on an action-related knowledge test when they previously learned both system and action-related knowledge, compared to participants who learned only action-related knowledge. Likewise, if action-related knowledge facilitates the acquisition of effectiveness knowledge, participants should score highest on an effectiveness knowledge test when they learned system, action-related, and effectiveness knowledge together, compared to participants who learned only effectiveness knowledge or action-related plus effectiveness knowledge. At the behavioral level, if system knowledge influences behavior indirectly through action-related and, subsequently, effectiveness knowledge, then effects on behavior-related variables should be strongest among participants who learned all three knowledge types, compared to those who acquired only action-related and/or effectiveness knowledge.

In this context, we recommend combining experimental approaches with other designs to gain a more complete understanding. Correlative, mediation-focused analyses can additionally examine mediation pathways described above. Longitudinal study designs can complement experiments by tracking changes in participants' knowledge over time (Watts et al., 2019) and providing insights into long-term effects (Braun & Dierkes, 2019). This allows for a more nuanced analysis of how specific environmental knowledge types develop, and how these developmental trajectories relate to behavioral outcomes, while accounting for potential moderating and mediating variables. Finally, longitudinal designs enable the investigation of knowledge convergence, whether environmental knowledge, as a multi-dimensional construct, consolidates into a one-dimensional construct over time (Kaiser et al., 2008; Liefländer et al., 2014).

4.2.3 Targeted behaviors and outcome variables

A key issue in designing future experiments on environmental knowledge effects concerns the interventions' targeted behaviors, and the main outcome variables, which shape the environmental knowledge topic under investigation. In the present study, we focused on the consumption of animal products as high-impact behavior to mitigate climate change (Lacroix, 2018; Wynes & Nicholas, 2017). By assessing participants' self-reported consumption of animal products through portion sizes transformed into CO_2 emissions, we obtained objective, comparable data. An analogous approach was adopted by Morren et al. (2021) who weighted participants' reported ingredients of meals with values from life cycle assessments. Using such approaches in future research offer a promising avenue to enhance the reliability and comparability of consumption pattern, because they reduce potential biases and variations in ingredients and portion sizes reported by participants.

Another approach could address general pro-environmental behavior, focusing on both, low- and high-impact actions (e.g., Goldwert et al., 2025; Kolenatý et al., 2022). This would allow the function of effectiveness knowledge (i.e., the ability to consciously select among different behavioral options according to its mitigation impact; Kaiser & Fuhrer, 2003; Liefländer et al., 2015) to become more apparent than when focusing on a single behavior, where participants are already guided towards the intended behavior, irrespective of whether they have acquired effectiveness knowledge. Depending on the targeted behavior, additional predictors need to be taken into account that shape the complex relationship between knowledge and behavior, such as environmental concern (Kolenatý et al., 2022), attitudes (Baierl et al., 2022; Roczen et al., 2014), or values (Bolderdijk et al., 2013, Maurer & Bogner, 2020). Mediation and moderation models may be particularly useful for examining how, or whether, different forms of environmental knowledge exert effects (Goldwert et al., 2025; Kolenatý et al., 2022; van Valkengoed et al., 2022).

4.2.4 The sample under investigation

In all these considerations, the sample plays an important role, as it influences the development of the intervention with regard to learning material difficulty, learning format, social norms, and the feasibility of the targeted behavior change (Bamberg & Möser, 2007; Goldwert et al., 2025; Hattie & Donoghue, 2016). Although previous research indicates that environmental knowledge is generally poor across all age groups (e.g., Braun & Dierkes, 2019; Geiger et al., 2019; Morren et al., 2021), we see particular potential in focusing on secondary school students. It can be assumed that all environmental knowledge types, or environmental knowledge in general, are still underdeveloped in this group (Braun & Dierkes, 2019; Geiger et al., 2019; Otto & Kaiser, 2014). As a result, potential effects of knowledge interventions may be larger. Furthermore, focusing on a heterogeneous sample, including gender and social-economic background, but also participants from both the Global North and Global South, would allow drawing conclusions on the generalizability of the findings (Henrich et al., 2010).

4.3 Conclusions

Our study overcame the limitations of previous, mainly correlative research on the effects of different environmental knowledge types on pro-environmental intentions and behavior by using an experimental approach to establish causal insights. Our findings do not provide clear evidence regarding the validity of the three types of environmental knowledge and differential effects on behavioral intention and behavior: The results suggest both, the importance and the lack of influence of knowledge quantity in shaping pro-environmental intentions. To further study the structure of environmental knowledge and the differential relationships of knowledge types with pro-environmental behavior, further experimental studies are crucial for a comprehensive understanding of its impact. These outcomes can offer valuable recommendations for practitioners and policymakers, helping them avoid over- or underestimation of knowledge transmission's impact. Our experimental setup provides a valuable foundation for future studies on the role of environmental knowledge in shaping sustainable dietary behavior and other pro-environmental actions.

5 Open science statement

The study was preregistered at https://doi.org/10.17605/OSF.IO/9YHVK and was conducted in accordance with this preregistration unless otherwise specified. We confirm that our paper includes all studies that we have conducted on this research question and that we have reported all measures, conditions and data exclusions. As the sample size was based on convenience, no formal rationale was provided in the preregistration. The used material, all data and R scripts can be downloaded at https://doi.org/10.17605/OSF.IO/GN3TZ.

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Appendix

Table A1

Descriptive Results for Covariates and Dependent Variables

	Knowledge condition				
	SYS	SYS+ACT	SYS+ACT+EFF	ENV_UNR	SYS+SYS+SYS
Pre-consumption[a] (*N* = 304)					
M (*SE*)	11.64 (9.85)	10.90 (10.11)	11.87 (11.52)	10.07 (7.49)	13.31 (12.49)
Md	9.51	8.55	8.49	8.69	8.85
Affinity[b] (*N* = 304)					
M (*SE*)	2.58 (0.80)	2.40 (0.83)	2.38 (0.86)	2.40 (0.88)	2.40 (0.92)
Md	2.60	2.40	2.20	2.20	2.20
Intention[a] (*N* = 304)					
M (*SE*)	8.72 (9.15)	7.61 (7.77)	7.45 (9.08)	8.60 (7.58)	7.90 (6.74)
Md	7.34	5.50	5.16	7.42	6.04
Sandwich topping (*N* = 250)					
vegan	14 (25.45%)	24 (48.00%)	19 (37.25%)	15 (31.25%)	19 (41.30%)
cheese	22 (40.00%)	16 (32.00%)	18 (35.29%)	20 (41.67%)	11 (23.91%)
chicken	9 (16.36 %)	8 (16.00%)	10 (19.61%)	7 (14.58%)	12 (26.09%)
beef	10 (18.18 %)	2 (4.00%)	4 (7.84%)	6 (12.50%)	4 (8.70%)
Meat[c]	19 (34.55%)	10 (20.00%)	14 (27.45%)	13 (27.45%)	16 (34.78%)
Chocolate (*N* = 189)					
vegan	20 (48.78%)	20 (58.82%)	23 (60.53%)	16 (42.11%)	21 (55.26%)
milk	21 (51.22%)	14 (41.18%)	15 (39.47%)	22 (57.89%)	17 (44.74%)

Note. SYS: system knowledge, SYS+ACT: system- and action-related knowledge, SYS+ACT+EFF: system, action-related, and effectiveness knowledge, ENV_UNR: environment-unrelated knowledge, SYS+SYS+SYS: high system knowledge. Relative frequencies (percent) calculated per respective condition.
[a] Pre-consumption and intention were operationalized by CO_2 emissions score (in kg) for their typical consumption of animal products before the intervention, or respectively, their intended consumption of animal products. [b] Theoretical range between 1-5. [c] Meat is the sum of vouchers for chicken and beef toppings and was used as the third category for the dependent variable sandwich topping choice, along with vegan and cheese toppings, because the cell population was too small for beef toppings.