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Technology in Nature—mDGBL as a Successful Approach to Promote Complex Contents?

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Abstract: The central challenges of our time mostly share a high level of complexity, which makes them unsolvable by single-perspective approaches. To offer adolescents the educational concepts that enable them to take various perspectives, comprehend, and finally deal constructively with these problems, innovative measures must be created. Additionally, the benefit of these measures must be shared equally by all learners, without being limited by their individual biographical or attitudinal characteristics. In this work, potential concepts were collected from geography education, technology education (TE), and education for sustainable development (ESD), and merged into a multi-perspective educational approach with mobile digital game-based learning (mDGBL) for the promotion of environmental and technology-related content. In the presented study, the accumulation of n = 94 Hessian students' subject-specific knowledge (SSK) was evaluated in a comparative study with a control group, along with the potential influence of gender, age, and concept-related attitudes (CRA) in a longitudinal quantitative study. Firstly, in a study of this kind, in addition to the approach's short-term success, the long-term effects on subject-specific knowledge were also tested. The results prove the full success of the innovative mDGBL intervention. There were strong immediate and long-lasting effects on participants' SSK, measured right after and eight weeks after the intervention. It could be proven that, although there were partially significant gender differences in attitudes towards modern technologies, learning success was not influenced by gender, age, or any of the measured attitudinal dimensions.

Keywords: mobile learning; DGBL; multi-perspective; geography education; ESD; NEP; MTAI

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1. Introduction

Some people think the use of modern technology and digitalization are to blame for youth's disconnection from nature. They fear that *screen time* is killing the *green time* and argue for the need for *digital detox* [1–3]. There are indeed studies that show the growing influence of modern technologies on young people's lives, as so-called *digital natives* [4,5]. But according to the youngsters themselves, they do not see a competitive situation between nature and technology, but much more the potential for synergies. To name one example, 71% of young people believe that nature conservation should try to make better use of the opportunities offered by digitization [6]. Considering nature and environment and modern technology as two opposing poles could be counterproductive when it comes to developing contemporary solutions for global problems [7].

As studies suggest, youth's prevailing paradigm about nature and the environment is rather positive [8,9]. Therefore, there seems to be a missing link that enables largely conscious and motivated young people to interact purposefully with their natural environment. As a possible reason for their prevailing distance from nature, Brämer and Koll (2021) [10] list the lack of access options. In this context, the authors of two independent nationwide studies on German youth conclude that need for experience-orientated educational activities is obvious and that the support of modern digital tools might bear the greatest potential for their successful implementation [6,10].

Ways still have to be found to effectively integrate new digital media into everyday school life [11], while for modern geographers and environmental scientists, digital measurement and information technologies, as well as machine learning and data science, have long become part of their daily routine. In particular, the latest technologies have enabled the development of completely new areas within geography, such as remote sensing or digital climate and landscape modelling, which have the potential to expand the field of education with contemporary and application-related content [12,13].

The perception that, in the past, mostly ecological aspects were considered when it came to discussions about education for sustainable development (ESD) [14] prevents a consensus on our need to simultaneously protect the environment and responsibly steer technological progress [15]. Recent publications on the topic already argue that, just as is already the case with environmental science education, technology education (TE) must also be seen as an integral element of modern and successful ESD [7]. Still, anchoring technological content in today's education appears to be an extensive challenge. While there has been a great effort to broadly implement environmental science education as part of ESD in most educational curricula in developed countries [16], TE is still limited to specific educational formats or subjects. Even then, most subjects only use digital technology as educational media for pedagogical purposes or focus on its functions alone, without providing a connection to any environment or sustainability content [14,17]. Therefore, innovative didactic approaches might have the potential to start at the intersection of ESD and TE in order to provide interlinked scientific, environmental, and technological literacy.

Ultimately, it is geography that, unlike other subjects, provides a framework from the outset to teach traditional science and modern technology in combined approaches [18,19]. Therefore, geography lessons are in the best position to implement converged ESD with TE by keeping technology not only as an educational medium but also as an object of its content that needs to be critically examined in the context of its application [17,18]. This can, for example, be seen in the attempts to integrate geographical information systems (GIS) into school lessons [13].

In both of these specific areas of geography education, ESD and TE, the reduction of the topic's inherent complexity remains a central challenge [20,21]. A promising approach to comprehending complex content is the conscious change of multiple perspectives. According to Schmayl (1995) [22], the focus of multi-perspective approaches should be on the learner's personal development, including examining objects, understanding their functions, and assessing their meaningful use. Furthermore, serious games or game-based learning approaches, depending on their designs, can provide frameworks that still are closely related to reality but at the same time differentiate themselves from real life's complexity by being strictly limited in both structure and content [23]. Besides these benefits, the approach of digital game-based learning (DGBL) has proven to be a way to provide motivation to keep learners focused to absorb, process, and retain important content while gaming [23,24].

Smart personal devices with wireless interfaces and built-in sensors allow any place to become a learning experience location [24,25]. In the context of geography education, mobile interfaces between a real and a digital (learning) world have proven to enable location- and context-sensitive mobile learning activities [26]. Mobile digital game-based learning (mDGBL), therefore, is no longer limited in space but allows any rural, urban, or natural location to become a "modern classroom".

Nonetheless, just because almost everyone in today's youth has a smart device and theoretical access to extracurricular environments, this does not guarantee that the mDGBL approaches are equally suitable for everyone. Whether they are categorical gender differences or diverging individual attitudes, personal inequalities are always to be expected. It has to be assumed, therefore, that the concept-related attitudes (CRA) of the individuals towards the topics treated, the locations visited, or the methods used will differ from one another and that, in addition to biographical factors, these affective attributes could affect cognitive learning success [27,28]. Therefore, it should be a quality feature of an educational unit to reach everyone in its target group equally, by considering the diversity of individual prerequisites and identifying their impact on educational outcome.

In conclusion, we found it necessary to follow a new approach to creating and testing innovative educational mDGBL settings for TE and ESD in geography education. In contrast to previous research in the field, we also aim to be the first to focus on long-term learning effects and the solidity of the approach. The latter means we aim to create and evaluate an educational framework that works for a specific but still heterogeneous target group regardless of their individual requirements. In this article, we first want to discuss the theoretical and subsequently methodological components of a specific concept (the SENSO Trail) that meets the above-named requirements. We define the expected learning effects on the subject-specific knowledge of the participants and carry out an empirical comparison with a control group. In addition, we identify possible factors that could possibly jeopardize the broader applicability of the approach and test their actual influence. After a detailed presentation of our results, they are reflected in a discussion, and a conclusion is drawn.

2. State of Research

Mobile DGBL approaches are well suited to the context of geography and ESD in various settings, and the associated transfer of subject-specific knowledge (SSK) seems to be very successful [25,26,29–34]. While many studies in this field focus on immediate knowledge gain, there are still no studies examining any long-term retention of what has been learned [32,33].

Cheng et al. (2013) [34] investigated primary school students' acceptance of technology by applying DGBL to environmental education and found that their acceptance will directly be influenced by their perceived ease of use and their attitude towards the technologies used. The authors of this study assume that these parameters also influence the learning outcome, but without being able to present any evidence. Van Eck's (2006) [35] criticism that the majority of research is limited to the efficiency of DGBL approaches is still justified today and also applies to mDGBL: it seems that scholars in the past have dwelt primarily on proving that their approaches work, rather than going a little further and answering the question of why, or rather, under what circumstances do they work and under what do they not. One sort of potential success factor—such as the chosen location, the specific setting, the structure of the intervention, or the tools, technology, and media used—could be classified as external parameters. In contrast to these setting- or application-related factors, however, there are also internal, learner-related factors that could affect the intervention. Most obvious to name are biographical factors such as age or gender [36]. But it is also conceivable that the success of the intervention could vary depending on the extent of affective (e.g., CRA) or cognitive (e.g., prior SSK) characteristics of the participants [28].

There is a direct connection between the affective attributes of a person, e.g., their attitude, and their cognitive performance, such as the accumulation of SSK [27,28,37].

Holbrook et al. (2005) [38] suggest that the perceived importance of an object has a positive effect on the accumulation of knowledge about it. Fremerey and Bogner (2015) [39] conducted a study with 5th to 7th graders in an extracurricular lesson on environment-related topics. They identified significant correlations between only some environmental attitudes (ecocentric) and the newly acquired knowledge, while other (anthropocentric) attitudes did not seem to correlate at all. A subsequent study even proved this connection with both dimensions for 10th graders [40].

In our case, this potential connection between attitudes and knowledge accumulation seems to become even more relevant, since the attitudes do not only refer to the content itself but also to the chosen setting, the tools, and the materials used [41]. The influence of people's CRA could therefore be decisive if they are to learn something about technology-supported research of forest ecosystems while being in a real forest and actively using modern technological devices.

Attitudes might also vary between genders. This is not a rare phenomenon, as plenty of empirical evidence shows [6,10,42]. In studies of environment- and nature-related attitudes, it is more often females who bring more emotional connectedness to nature and pro-environmental attitudes with them, while males seem to be more reserved [6,43]. The gender gap in attitudes toward modern technology is discussed even more [44,45]. Here, males are mostly described as more tech-savvy and females as more reserved in their attitudes toward technical objects and topics [44–46]. Bengel and Peter (2021) [42] were recently able to distinguish the attitudes of university students toward modern technology into three different dimensions: cognitive, affective, and behavioral attitudes [28]. They found that females only showed higher perceived intimidation (affective dimension) with or through modern technology, while the cognitive and behavioral dimensions of their attitudes did not differ from males.

Not only indirectly via attitude, but also directly when it comes to the suitability of educational approaches, gender differences in the performance of participants could become apparent. Even if modern society is very interested in dissolving historically implemented gender stereotypes related to disciplines like technology and natural sciences, it must be considered that they still exist. A study presented by Dresel, Schober, and Zeigler (2007) [47] showed that around 40% of the parents surveyed made stereotypical attributions about the natural sciences, and this had measurable positive and negative effects on their sons and daughters. Benke (2012) states that:

> the natural sciences are part of the cultural heritage and are also very present in public discourse [. . .]. [They] are not a gender-free zone, but [. . .] historically male. For this reason, gender-equitable subject didactics cannot avoid dealing with gender and the stereotyping of science. [48] (p. 217)

Although boys are often assumed to be fonder of or more experienced with technology, computers, and digital games, it does not always affect their performance in learning. This is shown, for example, by a study by Papastergiou (2009) [49] in which 16- to 17-year-old Greek boys and girls performed equally well in a knowledge test on computer memory after they had previously taken part in a digital learning game. The results of Bätz, Wittler, and Wilde (2010) [36] suggest that girls, on the other hand, tend to show higher degrees of motivation and knowledge gain in extracurricular settings. Although there is proof for DGBL concepts to be suitable for the participants regardless of their gender or the level of their previous experience [34], there is still a lack of data that would allow any statement to be made about the gender robustness of mDGBL approaches. It is therefore necessary to determine whether there are gender differences in the considered approaches and whether those have or do not have demonstrable effects on learners' performances.

The gaps in the current research outlined above are addressed in the following research questions for this study:

- Q1. Does a mobile DGBL approach for ESD and TE have a sustaining influence on students' SSK?
- Q2. Do affective factors such as attitude towards
  - Q2.1. nature and environment or
  - Q2.2. modern technology or
- Q3 Biographical factors such as
  - Q3.1. age or
  - Q3.2. gender

have any significant effects on students' SSK acquisition during participation in the mobile DGBL approach for ESD and TE?

3. Materials and Methods

The SENSO Trail (Science Education and Natural System Observation) is implemented in the research and educational forest of Philipps University of Marburg in Germany. SENSO Trail is an educational concept in which approaches from digital nature trails, geocaching, open-air science education, and mDGBL are combined into an innovative adventure trail. The project was funded by the Hessian State Ministry for Higher Education, Research, and the Arts, Germany, as part of the LOEWE priority project Natur4.0—Sensing Biodiversity. In Natur4.0, natural and environmental research and modern technology are combined with approaches and perspectives from multiple disciplines on different scales [50,51]. For example, the physiology of a tree (1) is considered on an individual small-scale level first [52]; in the following step, it will be linked to the prevailing microclimates (2) on and around the tree [53]; and finally, in a further change of perspective, the tree's role as a habit and its interaction with the animal world (3) is captured [54]. To combine several of these selective insights and to upscale them into a higher-level view of the whole ecosystem, the use of machine learning methods, A.I. (4), and remote sensing (5) come into play [55]. As can be seen in Figure 1, this selective consideration on varying scales within Natur4.0 was transferred into respective units of the SENSO Trail.

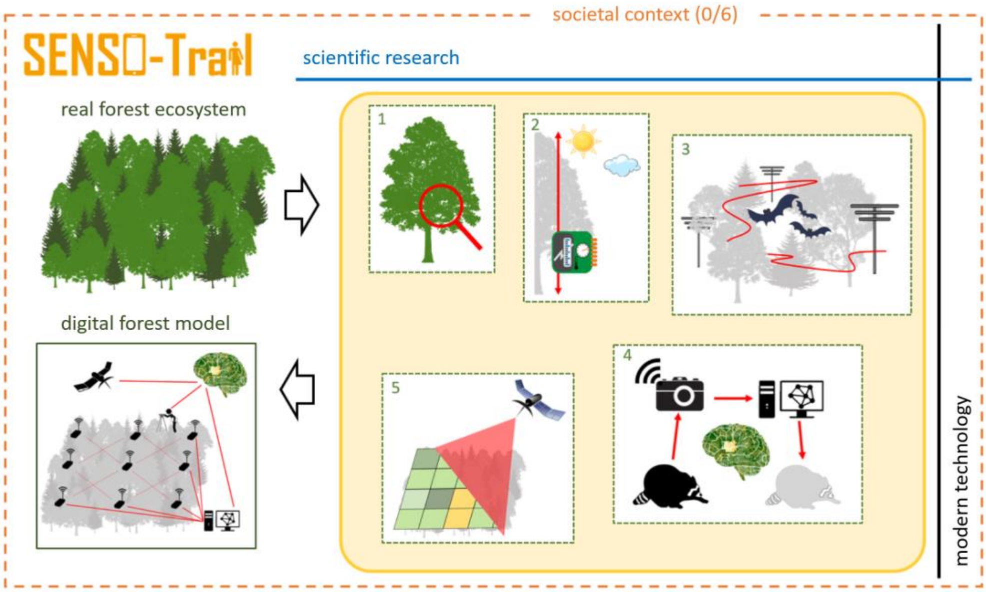

Figure 1. Simplified didactic concept structure of the SENSO Trail.

The trail follows a non-linear modular structure that has to be explored independently by using the SENSO app on tablets (Figure 2). Functions and content are unlocked successively as the participants progress and are added to their individual digital portfolios. The thematic distribution into six stations breaks up Natur4.0′s content complexity in a multi-perspective approach [22]. Investigation points (IPs) for each station complete the units by linking subject knowledge to the interactive use of technology and research methods. While important basic information on the relevant topic is conveyed at the actual station, this should find practical application in the IPs that are linked to each station. Here, actual data sets from Natur4.0 can actively be retrieved and reflected to keep the learning experience as close to reality as possible. In a final station (6), the content is reconnected and referred back to the societal context with a concrete application reference (the development of digital environmental models). A competitive character is deliberately integrated as a supporting game mechanism to promote learning effects [56]. In that sense, the participants are credited with research points for completed stations, IPs, and collected data [23].

The goals for successful participation are the expanded understanding of the biotic and abiotic environment on different scales, their mutual spatiotemporal relationships, as well as an idea of the complexity of natural systems [18,53]. Additionally, the promotion of awareness of scientific approaches and modern technology with their important roles in a deeper comprehension of complex causal structures is needed to identify and discuss the potential future of human–environmental interactions [7,18].

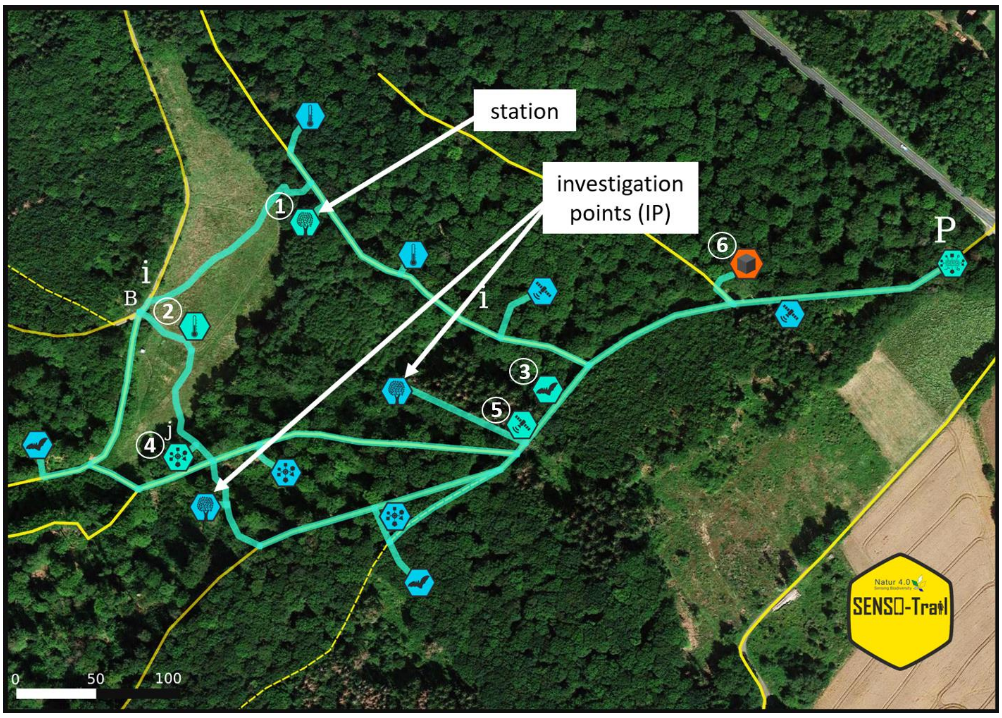

Figure 2. Map of the SENSO Trail area with green hexagons = stations; blue hexagons = respective investigation points; green line signature = proposed trail network.

Six school classes (German Gymnasium) from Hesse participated in 2021 in the presented study. In a cleaned dataset, a total of 94 subjects could be analyzed by their provided data: 43 females and 50 males with an average age of 15.62 years (min. = 14; max. = 18; SD = 0.86). A test group n = 66 (M = 5.85; SD = 0.83) and a control group n = 28 (M = 15.07; SD = 0.66) were created through randomized assignment. In this context, it must be noted that in the follow-up examination with n = 50, a slightly lower response was achieved than was the case with the first two enquiries, which were conducted on the date of the actual intervention, directly before (pre, n = 66) and after (post, n = 66). The data were exclusively retrieved via anonymized paper-and-pencil-style questionnaires at all three times of enquiry. No additional approval from our institution's ethics committee ("Kommission Forschung und Verantwortung") was required to carry out this study apart from the declaration of consent from the participants' legal guardians.

The participants could indicate their gender as male, female, or diverse; in this study, the diverse category was not chosen by anyone and is therefore not considered in our analyses. For reasons of good scientific practice, the age parameter was also recorded and analyzed, but in contrast to gender, due to a rather narrowly defined target group and a relatively low age spread in the sample, we have no indication that significant effects are to be expected here.

Several instruments for quantifying attitudes toward nature and the environment for adults, children, and adolescents exist in the literature [29,57,58]. While some limit themselves to certain ecocentric or anthropocentric dimensions (e.g., Bogner and Wiseman 2006 [58]), others follow a one-dimensional approach and aim to depict the ecological paradigm of the respondents as a whole (e.g., Dunlap et al. 2000 [57]). The latter includes, as one of the best-known instruments in the field, the New Ecological Paradigm (NEP) scale. Since its development over 40 years ago, it has been applied, adapted, and refined in various contexts [59,60]. The version of the NEP scale used in this research is an adapted variant of the 2000 scale (15 items, Cronbach's $\alpha = 0.83$) [57]. In addition to the translation into German, item 6 of the original set was inverted as a result of pretesting. We also found that this item had lower scores in other, independent publications as well, which even strengthened the decision for our approach [9].

The lack of comparable tools for measuring technology attitudes has recently been identified by Bengel and Peter (2021) [42] and responded to with the development of the Modern Technology Attitude Index (MTAI). This instrument maintains a more general perspective on attitudes towards modern technology by measuring three main psychometric dimensions of attitudes: cognitive, affective, and conative response behavioral dimensions [28,61], which, in this case, are intimidation (INT), loss of control (LOC), and benefits and easement (BAE). Since this instrument is still relatively young, there has only been one study so far, with pre-service geography teachers. The reported qualities (e.g., Cronbach's α = 0.83) indicated broad suitability beyond the bounds of the initial study, which, despite the compactness of the psychometric detail with only 14 items, fully qualified for the purpose of this study [42].

Like the biographical variables, the 29 chosen items for measurement of attitudes (15 NEP and 14 MTAI) were only used at the first time of enquiry. Each Likert-scaled item brought four possible answers: fully agree, tend to agree, tend to disagree, and strongly disagree [62]. The means of each scale or, in the case of the MTAI, subscale, were calculated as test values for the subsequent analysis [63].

Additionally, a set of test items was created to analyze the participants' potential SSK acquirements, stagnations, or even declines during the interventions and over time. Existing tests were viewed in advance but found to not fit the intended purposes, for reasons of either content orientation or scope [25,64]. Thus, 15 test items in direct relation to the promoted content were tailored to the needs of this study. The items were formulated in the form of either true or false statements that could be marked as true, false, or do not know. In the analysis, items that were marked correctly as true or correctly as false were treated as knowing, and items marked incorrectly as true, incorrectly as false, or marked as do not know were treated as not knowing. To quantify the actual gain in SSK that might be achieved through the intervention, a variable for knowledge acquisition was created by using the score differences of pre- and post-testing.

In the intervention study presented, the immediate and long-term learning success of multi-perspective mDGBL concepts should be tested as a first step (Q1), and then potential influencing factors on the actual acquisition of knowledge should be examined (Q2/Q3). As can be seen in Figure 3, at the first time of enquiry (TOE1), all participants were asked pseudonymized questionnaires about their biographical parameters of age and gender, and were presented with an identical knowledge test that related directly to the specific content (SSK) of the SENSO Trail. Since the test group's attitudes (CRA) towards nature and the environment (NEP) and modern technology (MTAI) as potential influence factors are of central interest for this study, they were also queried in an additional section. Corresponding parameters for the control group appeared to be less useful for this study and were omitted for reasons of efficiency.

The control group was offered an alternative extracurricular program instead. Although their intervention took place in the forest as well and was related to geography and natural sciences too, care was taken to ensure that there were no intersections with the SENSO Trail concept. At the second time of enquiry (TOE2), directly after participation, SSK was tested once more in both groups. Only for the test group, there was a third time of enquiry (TOE3) approximately eight weeks after participation. In this follow-up, the SSK was tested a third and final time to analyze the long-term effects of the intervention.

For data analysis, the free statistical software R and the additional program R-Studio, version R-4.0.2, were used for cleaning the data and the classic test theory was used for the construction of the instruments [65]. Descriptive methods, comparisons, and regression analysis were conducted with the free statistical software JASP, version 0.14.1 [66].

For the comparisons of the knowledge test performance within the test group over the three times of enquiry, an analysis of variance (ANOVA) with repeated measures was used together with a Greenhouse–Geisser correction for violated sphericity and a Bonferroni corrected post hoc test. Even if the development of new statistical methods and thus their variety is increasing, with ANOVA we have chosen an equally classic but reliable method to meet the needs of the statistical analysis of our data [67]. ANOVA of independent measures was performed to compare the knowledge acquisition of the test and control group to prove that possible knowledge acquisition was caused by the actual intervention and did not happen randomly. Omega squared was chosen to report effect sizes, since our sample size is rather small [67]. In a third step, multiple linear regression was used to test whether a fitting model can be created from the potential influencing factors of age, gender, or attitude (toward nature and the environment or modern technology) that can predict the acquired knowledge of the test group as a dependent variable. Additionally, another ANOVA was used to investigate potential gender differences within all the investigated variables. The level of significance was set at 0.05 [63].

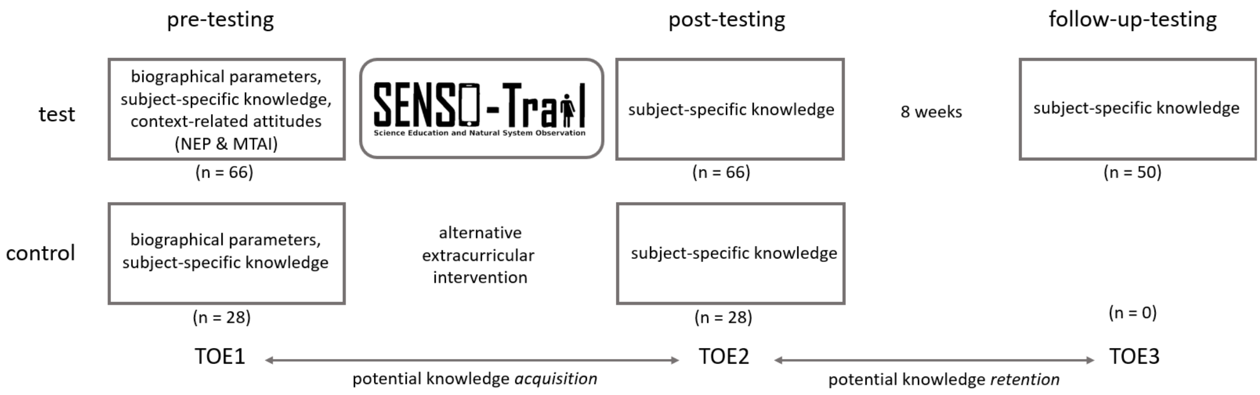

Figure 3. Research design.

4. Results

4.1. Knowledge Acquisition

The repeated measures ANOVA on the test group (n = 50) shows significant differences (F (1.55, 1.64) = 46.47, $p = 1.4127 \times 10^{-13}$, $\omega^2 = 0.26$) between the 3 times of enquiry (TOE1 to 3). A Bonferroni-adjusted post hoc test reveals significant higher performances at TOE2 ($M_{Diff} = -0.2272$, SE = 0.0258, t = −8.7932, $p_{bonf} = 1.5036 \times 10^{-13}$) and TOE3 ($M_{Diff} = -0.2020$, SE = 0.0258, t = −7.8198, $p_{bonf} = 1.8408 \times 10^{-11}$) compared to TOE1, while there are no significant differences between TOE2 and 3 ($M_{Diff} = 0.0252$, SE = 0.0258, t = 0.9734, $p_{bonf} = 0.9983$). As can be seen in Figure 4, in most cases the score after the intervention is higher than before and even stays on average the same level at the follow-up test (see Table 1).

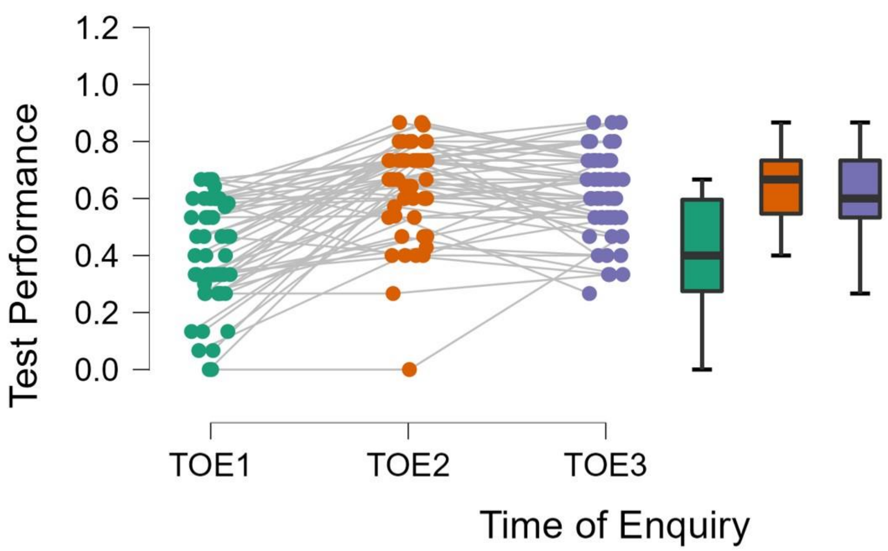

Figure 4. Performance on SSK of test group (n = 50) before (TOE1), right after (TOE2), and 8 weeks after (TOE3) the intervention.

Table 1. Mean scores of SSK (between 0 and 1) of both groups at the 3 times of enquiry.

Group	TOE1	TOE2	TOE3
test (n = 50)	0.404	0.637	0.609
control (n = 28)	0.402	0.402	- [1]

[1] at TOE3 no data were gathered for the control group.

Independent measures ANOVA showed no significant differences in prior knowledge (KN_PRE) of the tested content between the test and control groups (F (1, 92) = 0.0026, $p = 0.9593$, $\omega^2 = 0.00$), as can be seen in Figure 5. With regard to previous knowledge, the same prerequisites are given in both groups.

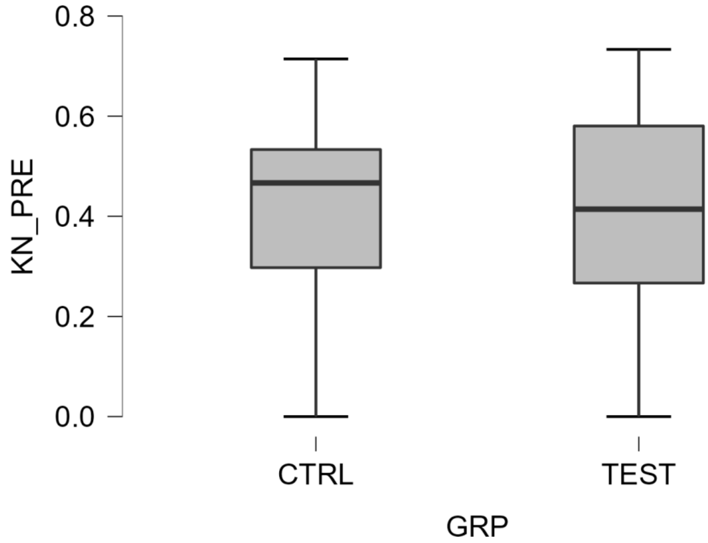

Figure 5. Knowledge (KN_PRE) of control (CTRL) and test (TEST) groups before intervention.

However, the knowledge acquisition (KN_ACQ) of the test group during the intervention is significantly higher (F (1, 92) = 24.3107.40, $p = 3.6182 \times 10^{-6}$, $\omega^2 = 0.20$) than in the control group (see Figure 6). Assuming the comparability of both groups, a random effect on the KN_ACQ variable of the test group between TOE1 and TOE2 can thus be excluded.

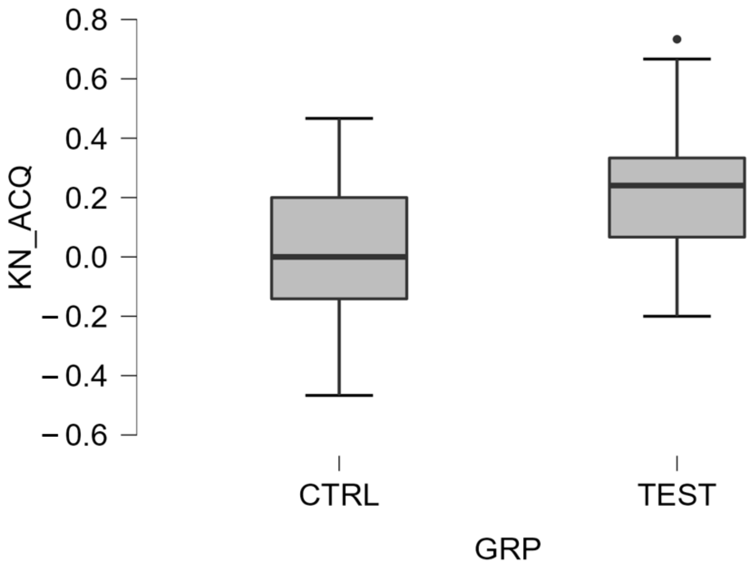

Figure 6. Knowledge acquisition (KN_ACQ) of control (CTRL) and test (TEST) groups during the time of intervention.

4.2. Descriptives for Potential Factors

4.2.1. Prior Knowledge

As can be seen in Figure 7, no significant differences in prior knowledge (KN_PRE) between the male and female participants within the test group could be found (F (1, 64) = 1.0857, $p = 0.3013$, $\omega^2 = 0.00$).

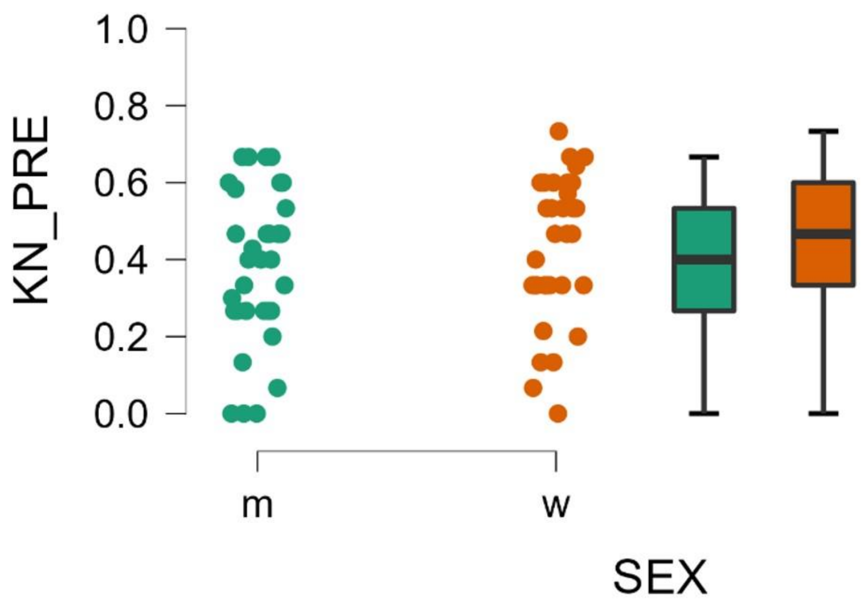

Figure 7. Knowledge of males (m) and females (w) before intervention.

4.2.2. NEP

The NEP scale's Cronbach's α was 0.78. On average, the participants showed high endorsement of the NEP with M = 3.295. Female participants might have gotten slightly higher scores (see Figure 8), but in the ANOVA no significant gender differences were found (F (1, 64) = 3.6344, $p = 0.0611$, $\omega^2 = 0.04$).

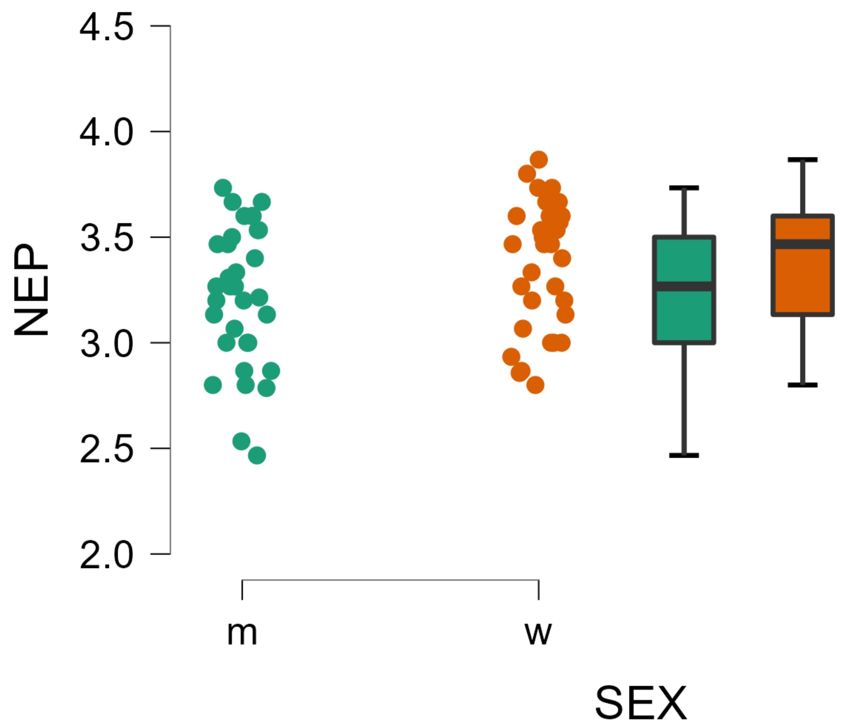

Figure 8. NEP scores of males (m) and females (w).

4.2.3. MTAI

The instrument's scales show good internal consistency (INT α = 0.81; LOC α = 0.72; BAE α = 0.83). On average, the score for intimidation was rather low, with M = 1.5417, together with the relatively high score on the benefits and easement scale (M = 3.2629) the average participant seemed to be more in favor of modern technology. Their attitude towards loss of control (M = 2.3316) on the other hand seemed rather balanced (compare Figures 9 and 10).

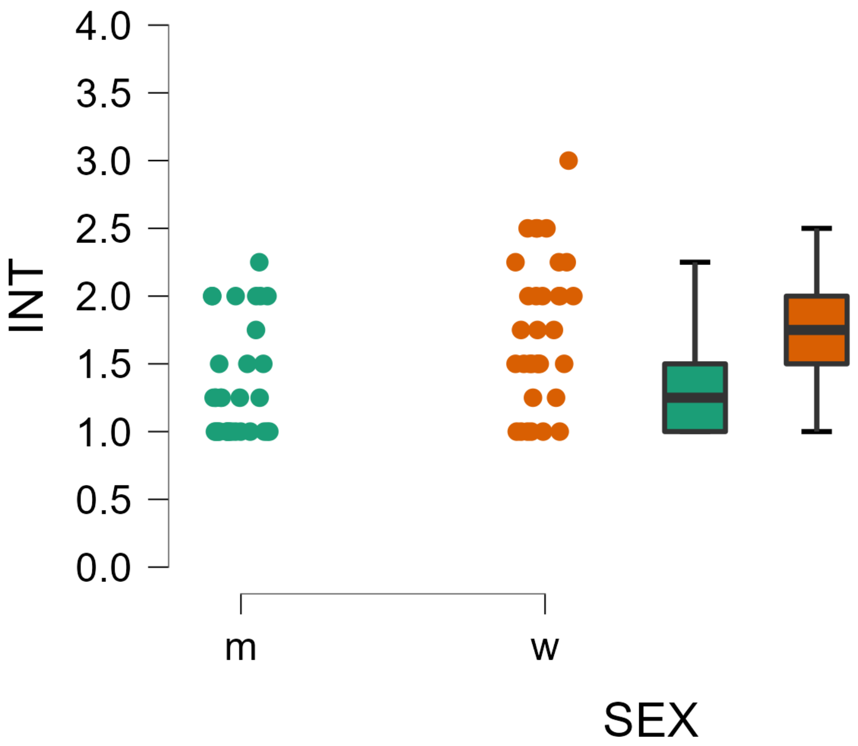

Figure 9. INT-scores of male (m) and female (w) participants.

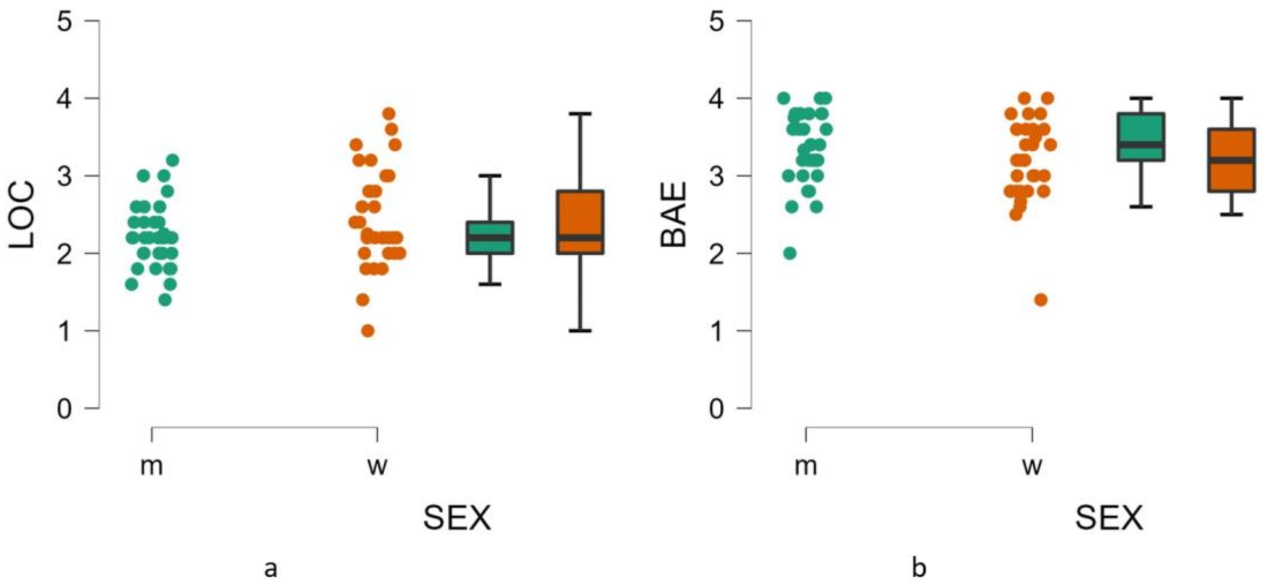

Figure 10. LOC (**a**) and BAE scores (**b**) of male (m) and female (w) participants.

Significant gender differences could only be found for the intimidation scale, where females seemed to perceive stronger intimidation (INT) than males ($F(1, 64) = 11.5123$, $p = 0.0012$,

$\omega^2 = 0.14$), as pictured in Figure 9. LOC (F (1, 64) = 2.8877, $p = 0.0941$, $\omega^2 = 0.03$) and BAE (F (1, 64) = 2.1974, $p = 0.1432$, $\omega^2 = 0.02$) did not differ significantly (see Figure 10).

4.3. Influence of Internal Factors

Multiple linear regression was used to test whether a model can be created from the potential influencing factors of gender (SEX), age (AGE), or attitude towards nature and the environment (NEP) or modern technology (INT, LOC, and BAE) that can predict the acquired knowledge of the test group (KN_ACQ). It was not possible to create a significant model by any constellation of the above-named factors as potential predictors. Conclusively, none of the tested factors seem to be significant predictors for acquired knowledge and can therefore be excluded as interference factors of educational success.

5. Discussion

We created and evaluated an extracurricular mDGBL education program for the transfer of complex content to test whether or not such approaches can have longer-lasting effects on students' subject-specific knowledge gain. Additionally, we asked if the intervention's general fitness might be limited by personal biographical or affective factors. Thus, we looked into the potential effects of age, gender, and concept-related attitudes on the knowledge acquisition of our test candidates.

Firstly, our data showed no significant differences in the participants' prior knowledge, neither between the test and control group, nor gender-related. Further, our results show a clear gain in the test group's knowledge during participation. Direct comparison with our control group confirms this and brings the results in line with comparable studies on mobile and/or DGBL approaches [24]. Additionally, since the participants' performance did not significantly decline over eight weeks, for the first time we have been able to prove a positive, long-term effect of this kind of educational concept.

With our second attempt, we were looking into participants' age, gender, and attitudes towards the related content to identify significant differences and analyze potential effects. The achievement of considerable alpha values despite small sample sizes on item numbers between 4 and 15 confirmed a rather good internal consistency of the NEP-Scale and MTAI, resp. it's three sub-scales. The adolescents' relatively high affection for nature and the environment, as we record it, was to be expected [9]. Environmental issues have an increasing presence in today's society; it is hardly possible to avoid confrontation any longer, whether you are interested in them or not [68]. This might lead to a generally high level of sensitivity among young people, which has probably risen since the development of the NEP scale. Unlike the results of comparable studies, a significantly higher affection of female adolescents for nature and the environment could not be documented [6,43]. This might already indicate the success of well-designed, gender-equal school and extracurricular awareness-raising measures that are now being offered to the young generations. Since a slight, albeit not significant difference can be seen in Figure 8, minor gender effects might be present, but would, for instance, only become apparent in bigger samples.

Attitudes towards modern technology were measured by the use of the MTAI in three psychometric dimensions. The perceived loss of control with or through modern technology seemed to be balanced within the test group, while the benefits and easement scale showed a rather high score on average. This could be interpreted to mean that teenagers today are generally more open to technology and feel empowered to use its advantages without being overwhelmed by it [4,5]. This assumption would be confirmed by the rather low average score of the participants' perceived intimidation through modern technology. In contrast to the first two scales, there is also a significant gender difference to be found, which in the overall picture reproduces the results already reported by Bengel and Peter (2021) [42].

Despite being able to identify this specific gender gap, neither that nor the parameter intimidation in general seem to affect the knowledge acquisition of our test group. This also applies to the other two dimensions of the MTAI. Contrary to similar studies, such as

Amry's (2014) [41], attitudes towards modern technology do not seem to influence participants' performance, although modern technology is a central theme of the intervention, both in terms of content and application. Neither could we reproduce any effects with nature and environment-related attitudes, as reported, e.g., in the studies of Fremery and Bogner (2015) [39] or Schneidehan-Opel (2020) [40]. However, it has to be considered that, in addition to the already mentioned discrepancies in the educational formats tested and other disparities, a different measuring instrument was used in their work. Additionally, neither age nor gender as biographic parameters could be used to predict the participants' knowledge acquisition through the intervention. These are extraordinary results since at least for gender there is plenty of evidence that might lead us to expect the contrary [36,43,47,48].

The present study had some limitations to be mentioned. Firstly, despite the potential disadvantages of statistical analysis of rather small sample sizes, none were experienced. Of course, assumptions such as, e.g., normal distribution of residuals were thoughtfully tested ahead of the main analysis. Additionally, despite the random distribution of subjects, there was a perceivable difference between the test and control group's mean ages. This was fully acknowledged but tolerated since the later analyses showed no effect of this parameter at all. The decreasing number of participants in the follow-up enquiry can be explained by the high level of preventive or health-related leaves during the COVID-19 pandemic at the third time of enquiry. Further, it has to be acknowledged that the measurement of SSK with 15 single-choice items can only measure a limited spectrum of the actual prior or later existing knowledge. A limited scale always has the logical problem that the more knowledge a participant already brings, the less capacity is left on the scale to be acquired. This phenomenon might not apply to reality, since there are plenty of knowledge areas and levels of deeper comprehension that could be accessed by learners but are not being tested. In our setting, the areas surveyed were severely limited due to study purposes, which could ultimately possibly lead to ceiling effects [69].

Extracurricular learning environments, as well as mDGBL approaches, are extremely diverse in terms of structure, content, and space, with various learning goals for different target groups. In our approach, we limited ourselves to specific parameters, as they coincided with the concept's content and setting. The results should therefore not be generalized and applied to other cases unwarily without the necessary reflection. Programs that implement similar didactic concepts deal with other topics where the personal attributes of their target group could possibly have a demonstrable effect. Nevertheless, we can state that there are mDGBL approaches that can equally be applied to heterogeneous target groups regardless of their age, gender, or CRA and still have immediate and long-lasting effects on participants' SSK.

6. Conclusions

The results of this study suggest that mDGBL concepts can be used to effectively address young people with multi-perspective approaches. This applies in particular to the intersection of different disciplines in complex contexts, as shown here using the example of the merging of natural ecosystems and modern technology in applied environmental sciences. The findings further reinforce the assumption that success, even with heterogeneous groups, is not limited by certain individual characteristics. This bolsters innovative educational approaches like ours, as innovative strategies are needed in modern education if our society wants to compete with the central challenges for a sustainable future. Since the SENSO Trail was tailored to a well-defined educational situation, further research in similar and different settings will be essential to strengthen the validity of these results. Further investigation into the success factors of mDGBL and multi-perspective approaches are needed to ensure the quality and even expand the scope of application for ESD and TE in geography education and beyond. Furthermore, in addition to the personal parameters, it might also be interesting to isolate selected external factors for an investigation of their potential influences on the approach's success. An example could be a comparison of physically implemented concepts, such as the one presented here, with purely virtual variants of multi-perspective mDGBL approaches.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are publicly available (accessed on 22 July 2022). The data that support the findings of this study are openly accessible in the research data repository of Philipps University at https://data.uni-marburg.de/handle/dataumr/167.

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