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Digital vs. Analog Learning—Two Content-Similar Interventions and Learning Outcomes

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Abstract: The digitization of classrooms has enormously changed teaching during the COVID-19 lockdowns. The rapid introduction of tablet classes subsequently raised questions about potential learning outputs, as only a few studies had produced quite contradicting outcomes. Consequently, our study was set up to monitor cognitive learning outcomes of conventional and digital teaching interventions by explicitly paying attention to short- and long-term knowledge retention rates. Both modules covered the very same classroom content in focusing on the curricular content of the forest ecosystem. Subjects were eighth-graders from seven Bavarian secondary schools (analog: $n = 74$; digital: $n = 225$). We analyzed the knowledge gained by applying a multiple-choice questionnaire (online, 25 items) in a pre–post-retention design. For the statistical analyses SPSS was used, and a Rasch analysis was based on the ACERQuest software (Version 2.1). The Rasch calibration of the ad hoc knowledge items assured solid scores ($Rel = 0.72$). Both interventions significantly increased knowledge (analog and digital: $p < 0.001$; Cohen's d: $d_{analog} = 0.59$, $d_{digital} = 0.42$) compared to the pre-test scores. Even after 6–9 weeks, there was no significant drop in the acquired knowledge scores (analog: $p = 0.619$; digital: $p = 0.092$) compared to the immediate post-test observed. Furthermore, there was no significant difference between the knowledge levels reached after both interventions. The knowledge scores showed typical learning profiles of earlier studies including its consistency even after several weeks. Since no significant differences appeared for the knowledge gain of both groups, the kind of teaching seemingly does not originate any influence independent of participation in the digital or analog module. The same seems to be valid for notebook entry options.

Keywords: ecology education; eighth graders; inquiry-based learning; sustainability; forest ecology; digital learning; collaborative learning; learning stations

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1. Introduction

Forests provide valuable resources such as timber, fuelwood, and food [1], thus, facing even more exploitation. If sustainable practices are not involved, the extraction of natural resources on a large scale for human consumption often leads to the degradation of forest ecosystems. These worldwide land-use activities are constantly reshaping the surface of our planet. The world's growing human population is putting increasing pressure on forest ecosystems, making ecosystem services and biodiversity of forest ecosystems even more vulnerable to human exploitation [2].

This results in significant biodiversity loss, a trend likely to continue [3]. Forest exploitation also disturbs the capabilities of forest ecosystems to act as carbon sinks [4]. Nature conservation initiatives must primarily gain long-term knowledge to understand these ecosystems. The responsibility for future conservation or climate change decisions needs exceptional support from the next generation. Sufficient knowledge bases are required to provide a solid foundation for relevant decisions with the intent to increase individual awareness and change individual behavior. In 2015, the United Nations defined the 17 Sustainable Development Goals (SDGs). They consider sustainable development as concordant with all involved relevant dimensions (economic, ecological, and social) and levels (global, national, regional, and local). The basis for them is the protection of ecosystems [5]. In order to reach these goals, appropriate educational programs are needed. Due to this relevance, the forest ecosystem has been included in the curriculum of all German schools [6–8]. To achieve the best possible learning results, a deep understanding of the effects of learning programs on cognitive achievement is required.

Educational programs are supposed to pass on relevant environmental knowledge [9]. Many classroom studies have shown such successful transfers, although the issue is a complex constructivist one, as knowledge construction demands active thinking by each learner and requires appropriate learning environments [10,11]. Constructivists claim learning is most successful through active hands-on activities [12]. Hands-on learning based on individual learning stations is seen as a suitable approach among many options to promote interest, motivation, and the ability to think critically about the environment [13]. Following this method of instruction, numerous educational initiatives in nature conservation have been demonstrated to be effective [14,15]. As learners work collaboratively in small peer groups at learning stations with self-instructional material, a teacher's role is modified to a mentor by indirectly impacting a student's learning process [16,17]. Studies have shown that these student-centered approaches may result in higher knowledge retention scores [18] or enhanced long-term learning [19]. Environmental education programs, particularly those emphasizing specific nature conservation aspects [20,21] or bird conservation [22], are reported to be successful when student-centered approaches are included.

In fact, studies of half-day and one-day interventions have shown long-term effectiveness, suggesting that a lengthy intervention is not always necessary for effective knowledge acquisition [23–25]. Especially with hands-on or cooperative focus, interventions consistently demonstrate significant positive effects on knowledge increase. Bogner [26] proved long-term effects even up to six months in week-long outreach intervention of a national park. Stern and colleagues [27] reported enhanced knowledge outcomes in a five-day program compared to a three-day program, both conducted in outreach facilities of a national park and reported consistent effects for up to three months. In a four-day environmental education program on water issues at an educational field center, Liefländer and colleagues [28] found increased environmental knowledge levels in all dimensions of the participants persisting over four weeks. Sellmann and Bogner [29] similarly observed a long-term knowledge gain for 10th graders participating in a one-day intervention on climate change. Within this context, it needs mentioning that one-day and half-day learning modules most commonly are implemented due to restrictive school schedules. However, multi-day learning opportunities are supposed to enable long-term learning and retention of knowledge even more effectively [30].

During lockdown enforcement during the COVID-19 pandemic, the digitalization of schools has progressed as alternatives disappeared dramatically. Digital tools suddenly had to substitute conventional classroom teaching, and tablet classes are no longer uncommon. Many teachers are still skeptical about this development, which is why questions about the learning success of digital instruction compared to traditional instruction have become increasingly urgent. However, the available studies are not conclusive in this regard.

Some studies highlight web-assisted teaching as superior to conventional classroom instruction. According to Benbunan-Fich and Hiltz [31], students when utilizing asynchronous web-based teaching tools (such as discussion boards) produced better final reports than face-to-face groups managed to achieve. Twigg [32] reported that online teaching tools have better test results compared to conventional teaching techniques. Similarly, Maki and colleagues' study [33] online versions originated better test results than identical face-to-face lectures. Furthermore, Connolly and colleagues [34] showed that online students consistently performed better than face-to-face students in a three-year quasi-experimental study of computer science students. One of the reasons for the better performance of the digital group in the studies might be that the students could repeatedly work through the materials independently at their own pace. Sometimes (e.g., Maki [33]) interactive quizzes or other supplementary materials were also offered while they were not available to the lecture group. Some other studies, however, demonstrated conventional classrooms are more effective than online ones: According to Wang and Newlin [35] or Motarella and colleagues [36], for example, in-person lecture students scored higher on the final tests than those who solely took online courses. The reason why the traditional students outperformed could be attributed to the fact that they had the chance to engage in direct interactions and seek immediate help from the teacher, unlike the remote students. Lastly, a third group of researchers stated differences between the two teaching strategies as insignificant. Waschull [37], reported online course versions with nearly equal outcomes compared to face-to-face courses. Kemp and Grieve [38] claimed that academic performance might be equivalent to engaging in face-to-face and online activities. Fiedler and colleagues [39] described a botanical/agricultural online module as similarly effective in learning gains as an on-site outreach. Similarly, Botsch and Botsch [40] reported no significant differences for a (political) science class, whether web-based or a traditional lecture was provided. Although the use of digital technologies in learning is often attributed a major role in public discussion, Hattie's recent meta-study, based on 130,000 individual studies, shows only minor effects that can be directly attributed to digital media [41]. For instance, the lack of significant differences observed could potentially be attributed to the possibility that the disparities between digital and analog interventions may be minuscule. A case in point could be the demonstration of a text in both interventions—when the only difference is the format (physical and electronic). Finally, it should be noted that many of the available studies concerning the differences in learning outcomes of digital vs. traditional teaching use final course grades for evaluation instead of standardized tests. One issue is that there is inconsistency in how teachers assess declarative knowledge, procedural knowledge, motivation, and other factors when assigning grades. This can be influenced by factors such as participation in extra credit assignments or the personal preferences of each teacher [36].

With such conflicting findings from studies concerned with digital teaching versus traditional face-to-face learning environments, our study followed three objectives: First, to clarify whether our syllabus-conform interventions lead to increased knowledge; second, to what extent this differs after an exclusively digital intervention from an analog intervention of the same content; and third, to analyze potential differences in retention performance between the two types of interventions.

2. Materials and Methods

In total, 299 eighth graders (digital: $n = 225$; analog: $n = 74$) of the college preparatory secondary school level ('gymnasium') participated in our study. Schools from urban and rural areas across Bavaria were included. More detailed information cannot be given due to permit restrictions.

Teachers enrolled their classes in our learning module, and students/parents gave informed consent to participate. For feasibility reasons (provision of materials, etc.), participation in the analog (control, $n = 74$) or digital ($n = 225$) intervention was not drawn by class but by schools. All students completed anonymized digital questionnaires covering content knowledge of the forest ecosystem and conservation containing 25 multiple-choice items (Table 1). Questionnaires were applied thrice (Figure 1): the pre-test (T1) was completed up to two weeks before the learning module, the post-test (T2) immediately after the learning module, and the retention test (T3) about six to nine weeks later.

Both learning modules were designed as Edu Breakouts (=Escape Games for educational purposes) for approximately four lessons and were carried out in one run or two double lessons. They included the same content (Table 1) but were prepared differently—one version followed analog procedures, and the other digital ones.

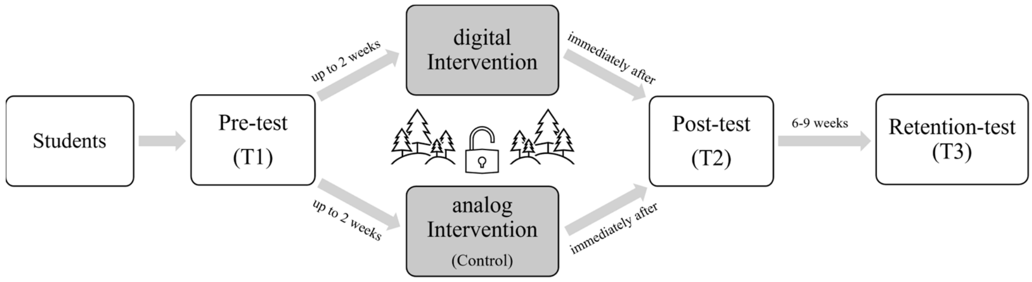

Figure 1. Study design including the timeframe of evaluation (T1, T2, T3; $N = 299$) for the digital ($n = 225$) and the analog group (control, $n = 74$).

Table 1. Subtopics and learning content of the learning modules.

Subtopic	Learning Content
The forest as an ecosystem	Students learn about biotic and abiotic environmental factors using the well-known example of the lake ecosystem and transferring them to the forest.
The layers of the forest	Students get to know the layers of the forest and conduct and evaluate an experiment on the water storage of the moss layer, followed by deepening exercises.
Species knowledge of forest trees	Students identify common forest tree species using a simplified identification key.
Succession and deadwood	Students learn about the process of succession and analyze diagrams and texts to evaluate measures for dealing with deadwood in forests.
Paper production and recycling	Students get an insight into paper production and resource requirements, recycling exercises, and evaluate common eco-labels related to their gain for nature.
The ecological footprint	Students calculate their ecological footprints using an online footprint calculator and evaluate behaviors related to its reduction.
Sustainability	Students learn about the three pillars of sustainability and clarify the terms "sustainable", "climate neutral", and "carbon neutral".
Protective functions of the forest	Students work out the direct and indirect protective functions of forests.
Pollution in the forest	Students evaluate different behaviors in the forests related to their harmfulness and learn about the degradation time of various trash items to reflect on their behavior.

Both short-term programs were supposed to cover a syllabus teaching unit that students autonomously completed in self-assembled pairs or small groups guided by the teacher. In the end, potential difficulties during the learning approach were reflected in class.

The analog version was designed similarly to a typical station learning [19], in which each station addresses a specific subtopic according to Table 1, with a gamified character using almost exclusively analog materials. All nine stations shown in Table 1 were offered twice to ensure an efficient workflow and were accompanied by a workbook. All stations could be accomplished independently because they focus on different key aspects (Table 1). Among other things, students experimented independently and protocoled their results. They discussed and evaluated consumption decisions and behaviors in the forest with their group members regarding their harmfulness to the forest with the help of information texts and graphics. By solving those and other various inquiry-based tasks, the students worked out a code at each station to open a lock of the locked chest containing a small reward. Sample solutions to the students' assignments were also available at the stations, ensuring that learning was self-directed [42] and self-controlled.

The digital version has an even more playful character than the analog version, as the students became part of an adventurous story. The students worked on tablets or computers and were guided through the story via various websites. The exercises are completed through learning games (e.g., assignments, puzzles, Hangman, etc.). However, practical tasks, such as experiments, are not possible. So, the results of the actual experiment were presented on an interactive pinboard in combination with some H5P applications. Thus, the focus in the digital variant was more on the evaluation and not on the execution and logging of the experiment as in the analog version. Also, discussions with group members, as in the analog version, are not mandatory here since potentially each student can work on the tasks at their own pace on their devices as wished. To progress through the story, they had to correctly solve multiple tasks that unlocked codes to open doors or objects. In contrast to the analog version, no handwritten assignments and backups were included. Depending on the student's final decision, the story has a different ending that shows them the consequences of their decision as an epilogue.

We applied a simple Rasch model for dichotomous items over all testing points to analyze the quality of our knowledge scale using the ACERQuest program [43]. The Rasch calibration resulted in a hierarchy of the items in terms of their difficulty and of the persons in terms of the individual person's ability estimates, in our case, a measure of the person's knowledge. Both were calibrated to 0. Positive values indicate higher difficulty for items and higher knowledge for persons; negative values indicate low item difficulty for items and low knowledge for persons.

For our statistical analyses, we used SPSS (Version 29.0). A total of 299 cases (T1, T2, and T3) have been included to extract dependencies between knowledge and digital or analog learning materials, resp. For analysis, responses to the knowledge questionnaire were recoded as "1" for correct and "0" for incorrect. We used the maximum likelihood estimates as an individual person's ability estimates from our Rasch analysis for further calculations.

As a model for knowledge acquisition, we chose a general linear model (GLM) for repeated measures. We used the person's ability estimates ("knowledge") as the within-subjects factor and the intervention type (digital/analog) as the between-subjects factor with three factor levels (T1, T2, and T3). Then, Welch tests (unequal variance *t*-test) were performed between the knowledge score differences T2-T1, resp. T2-T3 to compare the knowledge changes of the two groups (digital/analog).

3. Results

3.1. Quality of the Instrument

The Rasch analysis using the ACERQuest program [43] scored solid values for our knowledge scale and a Wright map (item–person map, Appendix A: Figure A1), which depicts an individual's performance ("X") as a function of item difficulty [44] was created. Knowledge items are displayed in logits, which represent the ratio of the relative frequencies of correct and incorrect answers: Higher positive logit scores indicate more profound knowledge. The knowledge scores ranged from −2.33 to 3.60 logits and were roughly normally distributed (M = 0.69, SD = 0.94). According to the separation reliability index, the scale was quite accurate in distinguishing students (Rel = 0.72). Fit values reflect the degree of disparity between the Rasch model's predicted and actual students' responses. The Rasch model's predictions showed a good fit to the knowledge item responses, with infit mean square (MS) values ranging from 0.83 to 1.24 [45].

3.2. Knowledge Changes

The correct answers of the digital group to the knowledge items in the pre-test scored a logit mean of 0.54 (±0.71), which significantly increased ($p < 0.001$) in the post-test to a mean of 0.88 (±0.92). The knowledge decrease from the post- to retention test (0.79 ± 1.00) was insignificant ($p = 0.092$). The analog control group started at a significant ($p < 0.05$) lower level (T1: $M(SD) = 0.32 \pm 0.83$) compared to the digital group. This difference can also be observed when plotting the number of cases against the pre-test scores. Although both samples are approximately normally distributed, there is a slight shift to the left in the analog control group and to the right in the digital group (Figure 2). Nevertheless, the analog group also showed a significant knowledge improvement in the post-test to 0.80 ± 0.88 ($p < 0.001$). The differences between the post- and retention tests were insignificant, as seen in the digital group (p = 0.619; T3: $M(SD)$ = 0.76 ± 1.00) (Figure 3). When comparing the pre-test and post-test, there was a medium effect (d = 0.59) for the analog version according to Cohen [46], and a weak effect (d = 0.42) for the digital version.

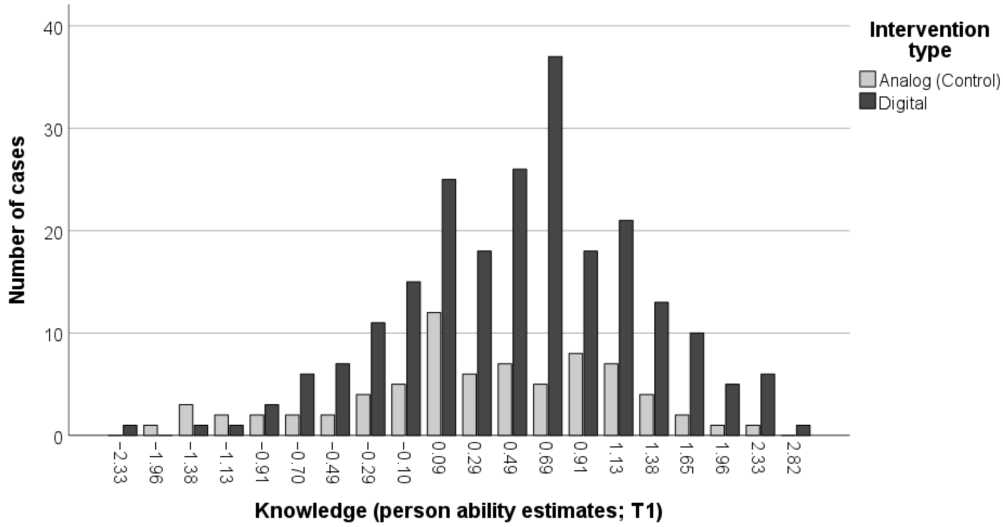

Figure 2. Distribution of the pre-test (T1) knowledge scores (person ability estimates based on 25 knowledge items) of the digital group (n = 225) and the analog control group (n = 74) as logits. Both samples are approximately normally distributed ($Z_{Skewness}$ = 0.91; $Z_{Kurtosis}$ = 2.81). Nevertheless, a slight shift of the analog control group to the left and of the digital group to the right can be observed.

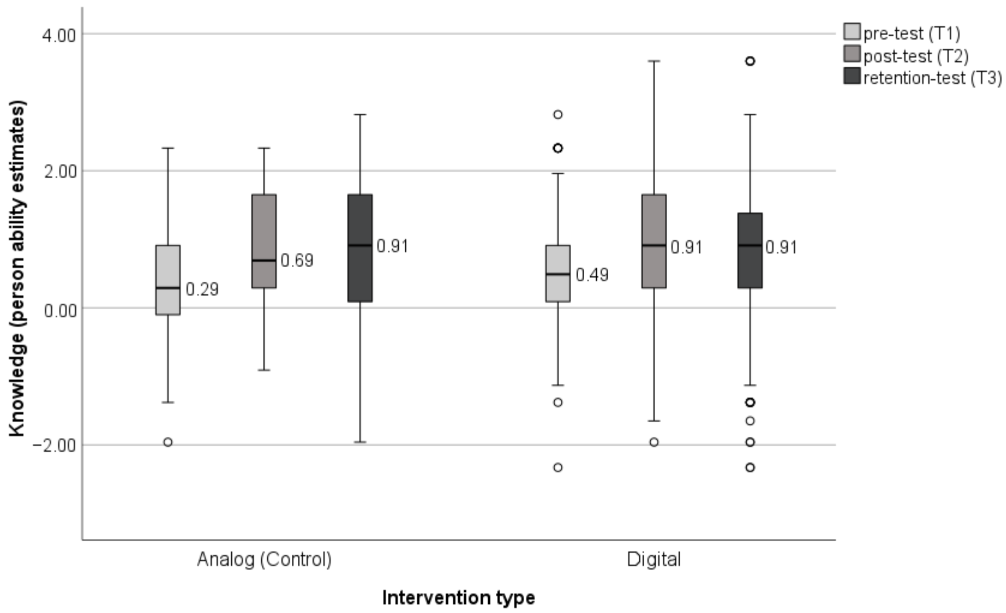

Figure 3. Boxplot of students' knowledge as individual person ability estimates with median scores of the digital group (n = 225) and the analog control group (n = 74) for all testing points. (T1: pre-test up to two weeks before intervention [Analog: $M(SD)$ = 0.32 (±0.83); Digital: $M(SD)$ = 0.54 (±0.71)], T2: post-test right after the intervention [Analog: $M(SD)$ = 0.80 (±0.88); Digital: $M(SD)$ = 0.88 (±0.92)], T3: retention-test (6–9 weeks after) [Analog: $M(SD)$ = 0.76 (±1.00); Digital: $M(SD)$ = 0.79 (±1.00)]; n = 299).

Following the recommendation of Rasch et al. [47], we applied Welch tests instead of two-sample t-tests in order to avoid unknown risks of type-I and type-II errors as indicated by pretesting. Further, there are quite unequal variances of the samples ($n_{digital}$ = 225,

n_{analog} = 74) which would lead to an unreliable Student's *t*-test according to Ruxton [48]. The performed Welch-tests between the knowledge score differences T2-T1 resp. T2-T3 comparing the knowledge gains between the two learning modules showed no significant differences (T2-T1: $t(303) = 1.178$, $p = 0.240$; T3-T2: $t(303) = 0.346$, $p = 0.729$; Table 2).

Table 2. Results of the performed Welch tests between the knowledge score differences T2-T1, resp T2-T3 of the two groups (digital intervention/analog intervention).

	n	*M*	*SD*	*t*	*df*	*p* (Two-Sided)
M_{analog} (T2-T1)	74	0.48	0.82	1.196	126.295	0.234
$M_{digital}$ (T2-T1)	231	0.35	0.84			
M_{analog} (T3-T2)	74	−0.04	0.75	0.353	127.304	0.725
$M_{digital}$ (T3-T2)	231	−0.08	0.78			

4. Discussion

4.1. Sustainable Long-Term Knowledge through Both Student-Centered Learning Modules

Since the effectiveness of many traditional teaching methods in promoting long-term learning and knowledge retention has been a subject of concern, establishing alternative strategies and techniques is supposed to enhance student's ability to retain knowledge over extended periods, such as (1) spaced learning and recurring learning opportunities, (2) retrieval practice, (3) multi-sensory learning, or (4) active learning. Our two learning modules focused on active learning. By actively participating in the learning process, students are supposed to enhance a deeper comprehension of the topic and retain knowledge for longer durations. Methodologies of active learning usually engage students in hands-on activities, collaborative working, group discussions, problem-solving exercises, inquiry-based learning, or interactive simulations.

We have tested our two learning modules regarding long-term learning and knowledge retention. As knowledge assessment is tailored by taught contents, a Rasch analysis needs to evaluate any (ad hoc) questionnaire's model fit. In our case, item difficulties and case logits were roughly normally distributed, and fit indices were within suitable ranges [44]. The same authors designated internal consistency scores such as ours as solid. As a result, the applied ad hoc knowledge questionnaire was shown to be suitable for the application of our learning module.

Both modules resulted in a significant increase in knowledge, which almost remained constant even after several weeks. The knowledge scores showed typical courses of earlier studies [49,50], which is a steep increase and slight dropdown after a time gap of 6 weeks. In consequence, students benefited from our learning module for the long term, i.e., even after six to nine weeks, although never back to pre-test levels. This aligns with earlier studies: Schmid and Bogner [51], for instance, demonstrated a significant knowledge persistence for a period of even 12 weeks following participation in an inquiry-based learning module. The students' learning due to inquiry-based teaching thereby appears to contribute significantly to the formation of long-term knowledge. Bogner [26] reported long-term effects after retesting knowledge levels even half a year after a week-long intervention in an outreach national park activity.

Our learning stations involved authentic content, which has been shown to increase students' interest, motivation, and critical thinking skills about local environmental issues [13]. This connection could have contributed to students' retention of newly acquired knowledge even several weeks later, as indicated by other studies. For instance, when comparing hands-on versus demonstrational teaching methods, Hartman et al. [52] described student engagement in hands-on activities as more successful in recalling abilities of newly acquired knowledge. These authors suggested that this may be due to the learning advantages of hands-on activities related to the multi-sensorial stimuli and the sense of accomplishment. Even more, Marth and Bogner [25] followed sixth-grade participants for one school year, describing a consistency of knowledge levels after six weeks; thus, the six-week level is a good indication of long-term learning.

Furthermore, our learning stations comprised inquiry-based and problem-based learning. The objectives of problem-based learning encompass assisting students to develop (1) adaptable knowledge, (2) proficient problem-solving abilities, (3) self-guided learning skills, (4) adeptness in cooperative activities, and (5) intrinsic motivation [53]. Problem-based learning usually is regarded as an integrative part of any inquiry-based learning strategies, which is an important part of science education. In this context, the word "inquiry" implies three distinct perspectives: (a) Researchers conducting studies through scientific methods. (b) Students actively learning through inquiry tasks as scientists do. (c) Educators offering suitable learning settings and assistance. Regardless of the perspective, the process of inquiry includes fundamental elements like posing scientifically focused questions, drawing conclusions based on evidence, or assessing other possible interpretations [54]. Since all these perspectives and elements can coexist in experimentation, inquiry-based learning, and related research very often involve experimentation. Considering distinct levels of education, the process of experimentation is an intricate scientific framework that students will gradually grasp as they progress through their educational journey [55]. At school, experiments serve multiple purposes including inspiring students, validating hypotheses, and demonstrating concepts [56]. For this, the teacher usually knows the result of the experiment, whereas the outcome of a research experiment is uncertain. We, therefore, distinguish the typical "school experiment", where concrete instructions are given and the outcome is known, from the "research experiment", which is a component of the scientific process. Nevertheless, the crucial factor in classroom teaching is whether the teacher has conveyed to students the expected outcome. Depending on the instruction given, the various levels of inquiry differ, e.g., structured, guided, open, or authentic inquiry [57,58]. The more steps of scientific knowledge acquisition are carried out by the students themselves, the more authentic the inquiry is. Considering the perspective of a teacher who implements inquiry-based learning, a significant hurdle is creating an environment in which students can thrive and effectively develop essential inquiry skills [59,60]. Five of our learning stations include guided or open inquiries and thus integrate inquiry-based learning as an active learning technique contributing to long-term learning and knowledge retention.

As in our case, cooperative learning modules enabled cognitive achievement and provided consistency with previous research [61]. Especially for complicated and abstract topics, student hands-on activities are associated with promoting effective learning through high cognitive activity [12], which may support a sustainable long-term knowledge level. For instance, experiments, simulations, and project-based learning may help students apply theoretical concepts and improve problem-solving abilities in STEM subjects [62]. Learning activities, such as learning stations with authentic materials, are considered beneficial for knowledge acquisition. Nevertheless, students performing tasks groupwise on tablets gained similar knowledge as during the hands-on learning activities. In consequence, hands-on learning activities do not seem the only essential triggers for efficient knowledge acquisition.

According to the body of literature, student-centered learning strategies may be more successful than teacher-centered ones, although the success of a given strategy relies on several different aspects. Learning approaches oriented on students' needs and interests promote cooperation and active engagement [63]. They enable students to take charge of their learning path, investigate original ideas, and improve their individual critical thinking abilities. For instance, Sturm and Bogner (2008) described student-centered approaches as far more effective than teacher-centered ones. Although retesting six to nine weeks after the intervention may involve logistical challenges, retention tests are essential since they indicate significant long-term learning progress in short-term interventions. The significant long-term knowledge gain originates most likely in our inquiry-based and student-centered approaches. This aligns with previous research on environmental conservation programs [20,22]. Randler and Hulde [64], for instance, found that students participating in hands-on experiments on soil ecology acquired higher knowledge scores than their teacher-centered counterparts four weeks after the program. Those studies demonstrate student-centered learning approaches as better improving academic performance and student engagement, even increasing motivation, and enabling better retention of information compared to traditional teacher-centered approaches. However, this may not be true for all learners since some prefer a more structured and directive learning environment [65,66]. In the end, a multitude of elements, such as subject matters, individual learning styles, teaching styles, and available resources, may contribute to effective learning techniques. The best strategy to encourage learning in a range of circumstances may be therefore a combination of student-centered and teacher-centered techniques.

4.2. Differences in Knowledge Acquisition between the Digital and the Analog Intervention

Although both our modules originated a significant and constant increase in knowledge, the pre-test difference between both subsamples was striking. This may originate in different levels of prior instructions at the respective schools. As already mentioned in the Materials and Methods section, the student's participation in the analog or digital intervention was for feasibility reasons (e.g., provision of materials, organization), not drawn by class but by schools. Therefore, the differences in students' prior knowledge may be due to differences in teachers' or school community's emphasis on sustainability and ecological contexts. These differences within the school communities could have contributed to deviating sample scores in prior knowledge. Schools actively involving nearby communities in environmental initiatives may provide students with practical experiences and applications in the real world. Collaborations with community projects, environmental organizations, or experts may accordingly enhance students' prior knowledge in these sectors [67,68]. However, those differences in prior knowledge could have also arisen from family, neighborhood, or peer backgrounds. Such out-of-school factors include differences in skill development during non-school hours, when children from socially advantaged families benefit from a cognitively stimulating home environment that, among other variables, also provides the means for a consciously ecological lifestyle [69,70]. However, the prevailing social situation and the importance of an ecologically sustainable lifestyle might also differ from region to region contributing to prior knowledge levels [71,72]. As our study was limited to learning success and curricular integration, administrative approval did not include monitoring such variables.

Although our participants in the digital module started at a higher level, they only reached slightly higher post-test and retention levels compared to the control group. This might point to a ceiling effect, where participants already begin with very high knowledge scores. Consequently, participating in a learning module cannot yield substantial knowledge gains among these students anymore. According to Staus and colleagues [73], usually, no conclusions can be drawn regarding the influence of an intervention on students' learning outcomes when ceiling effects occur, which may lead to an underestimation of the intervention's positive effects. Nevertheless, a significant knowledge gain was observed for both groups by proving both modules as effective. However, it does not seem to influence the students' knowledge gain whether the content is exclusively prepared digitally or analogously. This aligns with the study of Fiedler and colleagues [39] which due to the COVID-19 lockdown was forced to alter a botanical and agricultural module to online instruction, which nevertheless produced similar results for both the outreach and the virtual application. Schönfelder and Bogner [74] reported no significant difference between on-site and online learning. However, Ahel and Lingenau [75] emphasized an asynchronous online learning process and its practical benefits: online interventions are more accessible and fit more flexibly into students' everyday schedules. Accordingly, our findings suggest that choosing between analog and digital interventions is unnecessary. Still, we are aware that digital and analog learning is a very complex topic and drawing conclusions from our data alone might oversimplify this very multifaceted issue. Nevertheless, our study does provide some helpful insights. A variety of methods and media are superior to restricting individual ones. The use of different media and methods not only provides some variety in the lessons but also offers different ways of learning and prepares for the multimedia-based everyday working life. Smartphones or tablets are already part of student's daily life. There are both opportunities and challenges to implementing these gadgets in classes. Anshari and colleagues [76] highlight multitasks and multi-sources and point to its environmental friendliness while also pointing out everyday classroom challenges such as distraction potential, dependency, and a lack of hands-on skills.

Some teachers of our digital learning module were concerned whether their students would learn as much as their analog counterparts when they lacked hand-written assignments. In fact, studies suggest hand-written notes as supportive for learning in specific contexts: After comparing recall abilities and recognition of common words, Mangen and colleagues [77] concluded that when a person writes down words, it improves their memory compared to typing them. Mueller and Oppenheimer [78] described "laptop" students as less successful in lectures regarding comprehension, retention abilities, and conceptual understanding of the taught matter. However, in our case, such concerns were shown to be not relevant as our digital group gained similar learning scores compared to the analog control group. This similarity may be because the efficiency of handwriting depends on several variables, including the learner's preferences, the type of content being studied, and the learning environment. For several learning tasks, it may be more effective or convenient for some students to take notes using digital tools. Another potential reason may simply lie in the one and a half decade since that study, as students today may better have adapted to the digital world.

5. Conclusions

Both the digital and the analog learning modules improved knowledge levels which are quite in line with the body of literature. However, the lack of differences in the learning outcomes reached between our two groups does not follow common expectations. Our study focused on a comparison between one digital and one analog learning module. Although we have reduced the complexity of a multilayered and sophisticated topic, we cannot completely exclude the influence of specific side factors, such as differences between schools. Furthermore, due to COVID-19, we were limited in the number of participants for the analog learning module that we used as a control group. However, the obtained result, indicating an equal improvement in knowledge from both digital and analog learning modules, underscores the potential and the value of the diversity of educational approaches. It also highlights that modern digital implementations can be as effective as traditional analog methods in facilitating knowledge acquisition and vice versa. This finding has implications for educational design, as it enables educators to harness the benefits of both digital and analog tools to adapt to the possible learning environments of a specific location or to cater to a broader range of student's individual learning preferences and, therefore, enhance overall learning outcomes. As both implementations show similar potential, the inclusion of digital submodules may allow substantial enrichment of traditional programs (or vice versa), whatever might better fit into instructing intentions. Therefore, teachers can go for digital-only lessons without worrying about lower learning outcomes compared to conventional analog ones. This might be a welcome alternative while the students need training in media skills which they will desperately need for future professions. Nevertheless, as the literature body shows that a variety of methods and media is superior to conventional ones, no single method and medium are better per se: The variety and the reflected use are decisive.

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Appendix A

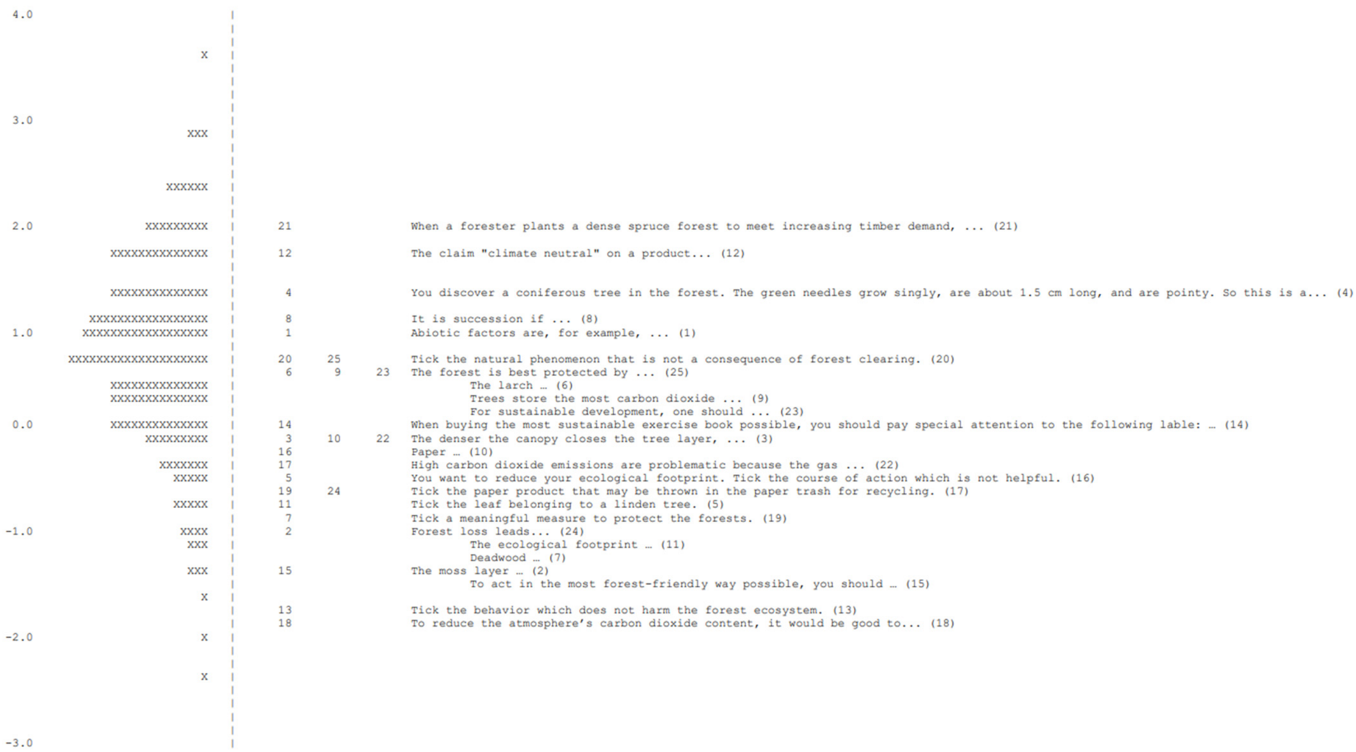

Figure A1. Wright map (item–person map) of the simple Rasch model analysis. The logit scale (left hand) indicates the measurement unit for the person's performance (X) and the item difficulty (item code, right hand). Each "X" represents six students.

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