Abstract: The relevance of experimentation in natural sciences and the importance of inclusion of all students are widely acknowledged. Successful scientific experimentation in the classroom is based on higher levels of science self-concept and appropriate instructions for completing the experiment. To facilitate the experimentation process, we developed a learning environment for magnetism with minimal barriers, aimed at fostering experimentation and self-concept development in dimensions such as language, visibility, and action. In a study involving 348 students from Grades 5 and 6 from German secondary schools, we investigated how students perceived the learning environment in terms of accessibility, how their self-concept in engaging with experimental instructions developed, and how these two concepts, accessibility and self-concept, are related. The results indicated that the students found the instructions of the digital learning environment to be accessible and showed a significant increase in self-concept when utilizing experimental instructions. It was also shown that the more accessible the students perceived the experimental instructions, the greater the increase in their self-concept with experimental instructions. However, only a small amount of variance was explained. This shows that such a digital learning environment can have positive effects on students, although the remaining open aspects (e.g., the specific support of low-achieving students) are being addressed and should be investigated in the future.

Keywords: inclusion; accessibility; science for all; digital learning environments; scientific literacy; experimental instructions

1. Introduction

In 2020, UNESCO ([1], United Nations Educational, Scientific and Cultural Organization) presented nine ideas about “Education in a post-COVID world”. One of these ideas was to “ensure scientific literacy within the curriculum. This is the right time for deep reflection on curriculum, particularly as we struggle against the denial of scientific knowledge and actively fight misinformation” [1] (p. 6). However, neither scientific literacy nor the discussion about ensuring it within the school curricula is a new phenomenon. In this context, Miller [2], for example, referred to a discussion that took place in the late 19th century. However, scientific literacy remained the preserve of an educated class until the 1930s. Nowadays, scientific literacy is included in the curriculum of most educational systems from kindergarten onward [3]. The OECD ([3], Organization for Economic Cooperation and Development) defines scientific literacy as the ability to understand scientific concepts, phenomena, and processes and transfer this content to both familiar and new situations. Scientific literacy is therefore relevant to understand scientific phenomena to actively make decisions without falling for fake news.
1.1. Scientific Literacy and Social Participation

Scientific literacy and the associated aspects of a positive self-concept are essential prerequisites for the social participation of students in science education [3] and in general for a participatory debate and democracy [4]. Adaptive learning environments are a good way of enabling all students to participate in scientific thinking and promote self-concept, regardless of their abilities. To be effective and foster scientific experimentation, adequate environments need to be designed in such a way to abolish physical, cognitive, linguistic, social, or other barriers to ensure access and participation for all students. Such environments foster subskills of scientific literacy such as engaging with the methods of scientific knowledge acquisition. Furthermore, these environments allow for experiences of competence and autonomy and can therefore positively influence self-concept [5]. Following the CRPD ([6], Convention on the Rights of Persons with Disabilities by the United Nations) with its demand for full equitable participation, science educators in schools must provide learning environments that allow for access to the experimental process irrespective of the students’ individual cognitive, sensory, emotional, or physical learning preconditions.

The demand for accessibility also needs to adhere to the corresponding instructions in experimental environments. Experimental instructions can provide students with structure, support, and scaffolds depending on their learning requirements. Accordingly, students should encounter experimental instructions that are both easily understandable and free from language barriers. Furthermore, these instructions should be visually clear and accessible to all students so that they can carry out experiments independently, meaning without any barriers regarding action. Based on the findings from learning and brain research, the Universal Design for Learning (UDL) represents a didactic framework that (1) addresses the individual learning requirements of the students and (2) creates variety and variability in the presentation of content and forms of action for the students [7]. In line with the UDL [8,9], the learning environments should consequently be designed in such a way that they can be used independently by all students without the need for special adaptations, designs, or versions, in other words, a learning environment that is suitable for all students.

We refer to the science for all framework [10] as a basis to ensure that all students are included. With the aim of developing a low-barrier learning environment, we were guided by two principles: (1) barrier-free information and (2) barrier-free communication facilities (action aspect). By barrier-free information, we mean the provision of information sources that are useful for the user and are accessible in terms of language, audio, and visuals. Accessible communication facilities enable participation in the action associated with the information. Accordingly, we developed the concept of accessible experimental instructions with the three dimensions: (1) action, (2) visibility, and (3) language [11]. Furthermore, we refer to a recently developed instrument to measure the accessibility of experimental instructions on these three dimensions (action, visibility, and language), as well as the self-concept in engaging with experimental instructions using these three dimensions [12]. Additionally, it is crucial for scientific learning environments not to foster stereotypes [13,14]. Science education in Germany in particular can support stereotypical ideas among students and thus have a negative impact on their self-concept. Prior studies have shown that girls and boys have different self-concepts in science and thus develop different interests [13,15], and gender differences play an important role in the way girls and boys perceive learning environments. Empirical studies showed that girls have a lower self-concept of ability in science [14] and lower interest in science [16]. Due to the combination of their lower self-confidence and interest in science, female adults are less likely to take up STEM professions later [17,18]. However, since there is a shortage of skilled workers in these STEM professions in Germany [18,19] and other industrialized countries [20,21], society cannot afford to keep women out of these professions. Instead, girls’ self-concepts and interest in the natural sciences should be promoted. Since domain-specific self-concept has proven to have a reciprocal effect on academic achievement [6,22],
it is important to foster students’ confidence in their academic abilities, which aims at enhancing academic performance [23].

As already indicated, accessible learning environments focus on students experiencing their autonomy and competence while experimenting. According to the self-determination theory [5], this should lead to higher learning motivation and, in a further step, should positively influence students’ self-concept of ability [24,25]. These positively perceived abilities, in turn, can lead to higher learning outcomes or school achievements [14,26].

1.2. Motivation for Science through Storytelling

Various methodological approaches are conceivable to promote students’ motivation in relation to science. One possibility is the use of storytelling [27–29]. Storytelling is a classic way of conveying values, ideas, concepts, and perceptions across generations [30]. Traditionally, fairy tales, for example, also had this aim. The stories told usually have a structure consisting of an introduction, a main part, and a conclusion [31]. By linking the content to a narrative story, the content can be better remembered and recalled later [30]. This allows the content to be communicated more quickly and effectively. In addition, the stories arouse attention [30] and interest [32]. However, it should be noted that students should always be able to clearly recognize which content is fiction and which content corresponds to reality [33]. This means that facts must be recognizable as such, and the storyteller must stick to the truth. The stories should also leave little room for interpretation to prevent misconceptions. In science lessons, a further advantage is that stories can also be used to focus on history and thus on the developmental history of the content area as well as on the duration of the acquisition of knowledge [31].

One way of realizing storytelling is through comics. Comics are a sequence of images through which a process or a story is told. The sequence of images can be used to emphasize complex content. Comics are also becoming increasingly popular, not only among readers, but also in research and explicitly in educational research [34–36]. Moreover, comics can foster motivation and enhance learning processes [35,36]. As a specific form of narration, science comics combine storytelling with a high proportion of images to convey scientific learning content [37–39]. Science comics thus combine the advantages of storytelling for imparting knowledge with the advantages of comics. Comics use a suitable combination of text and images that is largely superior to text-only learning [40,41]. The theoretical background of multimedia comic environments is formed by Mayer’s Cognitive Theory of Multimedia Learning [40,41] and the model of text and image comprehension [42]. Therefore, this suitable text–picture integration reduces the cognitive load, and further load-reducing aspects can be included, such as segmentation, signaling, individualizing, or accommodating students’ spatial imagination [43].

1.3. Aim and Hypothesis

The aim of the present study was to investigate the development of the self-concept in science during learning in a stereotype-free and barrier-free comic environment. The focus was on students’ perceptions of accessibility to the experimental instructions and on the development of their self-concept in engaging with experimental instructions on the three dimensions of action, language, and visibility. Our learning environment included two experiments on magnetism. We assumed that the accessibility of both experiments was high in terms of action, language, and visibility (Hypothesis 1). Regarding the development of the students’ self-concepts in engaging with experimental instructions, we assumed that their self-concept would develop in a positive way (Hypothesis 2). In addition, we assumed that the more accessible the learning environment was perceived, the higher the development of students’ self-concepts was (Hypothesis 3). This third hypothesis was based on the assumption that an accessible learning environment could foster self-confidence, well-being, and the willingness to participate actively [44]. In a stereotype-free comic environment, both girls and boys were addressed so that both could benefit from
this environment. We assumed that the girls’ self-concepts increase to the same extent as the boys’ self-concepts (Hypothesis 4).

Furthermore, in an explorative approach, we took a closer look at the development of students’ self-concepts and examined whether factors like school track (academic track vs. non-academic track) or the three facets of self-concept regarding experimental instructions (action, language, and visibility) had an impact on each dimension’s self-concept when working with experimental instructions.

1.4. Overview of the Results

Our comic environment comprised two experiments that had to be carried out according to the research cycle [45–47]. Accordingly, we distinguished between two sets of experimental instructions (see below). Overall, we saw that the accessibility was very good for both sets of experimental instructions within the newly developed learning environment (Hypothesis 1) [10]. Regarding students’ self-concepts, we found that in general, it was possible to raise their self-concept in engaging with experimental instructions [10] (Hypothesis 2). However, this was primarily due to the increase in self-concept in the dimensions of action and language. Regarding Hypothesis 3, we found that the more accessible the learning environment was to the students, the higher the development of their self-concept. Moreover, addressing Hypothesis 4, the self-concepts of girls increased to the same extent as that of boys. No significant interactions were found between the development of self-concept and gender; therefore, we can assume that self-concept developed similarly in boys and girls.

However, when analyzing action, language, and visibility, the perceived accessibility accounted for less than ten percent of the explained variance in the increase of all three dimensions of students’ self-concepts. The exploratory analysis presented in the present study revealed that the perceived self-concept at the first measurement and the respective accessibility of the experimental instructions had a significant influence on the self-concept at the second measurement.

2. Materials and Methods

2.1. Sample and Design

To determine the required sample size, we ran two power-analyses with G*Power [48,49]. For a MANOVA with repeated measures and within-between interaction and a priori assumptions, we entered the effect size of $f(V) = 0.25$, which resulted in $\eta^2_p = 0.06$ (small/medium effect), as a medium effect can be assumed, and a total required sample size of 210 participants. For a linear multiple regression with seven predictors and an assumed medium effect size of $f(V) = 0.25$, we received a total required sample size of 95 participants.

A total of 348 students took part in our study (48.1% girls and 51.9% boys). Due to absences and technical difficulties, the number of participants varied slightly between the three sessions. A total of 295 students participated in all three sessions. Personal data were only collected during the first session. On average, the participants were 11.3 ($SD = 1.28$) years of age and attended Grade 5 ($n = 157, 45.2\%$) and Grade 6 ($n = 191, 54.8\%$) at academic-track ($n = 155, 44.5\%$) and non-academic-track ($n = 193, 55.4\%$) schools in the Southwest of Germany. In the following we refer with $N$ to the total sample and $n$ to subgroups.

To gain knowledge about the development of students’ self-concepts in engaging with experimental instructions and their perceived accessibility of the experimental instructions, we set up pre–post-designs with an intervention. In the intervention, the students used an iPad to work with a newly developed digital scientific learning environment and conducted both experiments in a self-regulated way by following the experimental instructions implemented in the learning environment.
2.2. Material and Measures

2.2.1. Development of a Digital Learning Environment in Science Education

For the intervention, we developed a prototype of an accessible digital learning environment with stereotype-free properties. Our learning environment was geared toward science lessons, with a focus on physics in Grades 5 and 6, addressing the topic of magnetism. The first principles of magnetism, often introduced in primary school, are the basis for more advanced concepts, such as electromagnetism. Magnetism is therefore suitable as a bridge topic to deepen a common topic and, at the same time, familiarize students systematically and explicitly with the basic principles of experimentation through practice.

Utilizing a comic-style format, we leveraged the power of storytelling in learning [30,31,38,39] to foster motivation for scientific content. Hence, a story was told in which two pedagogical agents flew in a spaceship. The pedagogical agents returned from a journey to Earth with various objects, including magnets. Back on the spaceship, they wanted to investigate magnets and started by traveling back in time. During this journey through time, they visited historical naturalists or explorers. In this way, the students learned about the historical development of the subject area. After traveling through time, the two pedagogical agents visited a virtual laboratory and examined the objects and the magnet. To do this, the students were introduced to the research cycle and then investigated different objects with the magnet. Then, the pedagogical agents contextualized findings in everyday scenarios. After the experimental part of the comic environment, the students received further information to transfer the information they had learned to everyday situations and thus stimulate the development of higher-level problem-solving skills and the transfer of learning [50,51]. Students received personalized written summaries documenting their assumptions, observations, and providing historical context for future reference and classroom discussion.

On average, the students participating in our study spent approximately 30–45 min engaging with the digital learning environment.

Within the learning environment, accessibility and the avoidance of stereotypes were prioritized. This learning environment was designed as a digital platform to enable students to navigate through the material independently. To promote scientific literacy and facilitate independent learning, our platform was meticulously structured, offering step-by-step guidance, instructional videos, and two hands-on experiments aligned with the research cycle.

To familiarize students with the research cycle, enhance scientific literacy, and organize the experimental process, the research cycle was simplified into three phases: (1) the formation of hypotheses or the formulation of assumptions, (2) the execution of the experiments and documentation of the observations, and (3) the comparison of assumptions and observations, as well as the interpretation of the results. All students went through the experimentation, following the research cycle twice to ensure some level of repetition and practice within the research cycle and its different steps.

Within the learning environment, each of the three phases of the research cycle was assigned its own virtual room. Each virtual room of the research cycle was color coded, respectively, helping students in navigating the process [43]. The matching of the colors corresponded to the concept of color coding [43] and helped the students to make connections between different content more easily. In this case, the respective phase within the research cycle was linked to the corresponding action in the virtual space. In the first room, the students formulated assumptions. Then, students progressed to the experiment room where they conducted experiments, testing different materials for their magnetic properties. During experiment 1 (E1), students tested materials like screws, metal plates, or test tubes. During experiment 2 (E2), they tested euro coins. Due to the choice of everyday objects for investigation with a magnet, the experiments are suitable, non-dangerous, and can be carried out independently at school, during homework at home, or in distance learning. In the evaluation room, the students compared their assumptions with their observations and received summarized physical background knowledge.
2.2.2. Instruments: Questionnaires on Self-Concept and on Accessibility

In addition to the learning environment, the students answered questions about their self-concept in engaging with experimental instructions within the three dimensions of action, language, and visibility during the first (pre-test) and third (post-test) session. During the intervention in session 2, the students answered items on the accessibility of the experimental instructions to experiment 1 (materials, E1) and experiment 2 (euro coins, E2), again within the three dimensions. Both scales, self-concept in engaging with experimental instructions and the accessibility of experimental instructions, were developed, piloted, and validated by our research team [12] and used successfully in previous studies. For item examples and descriptive data on the scales, see Table 1.

Table 1. Accessibility and self-concept scales: reliability (Cronbach's alpha), number of items, and examples.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Dimension</th>
<th>Number of Items</th>
<th>Reliability (Cronbach α)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M1</td>
<td>M2</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Action</td>
<td>8</td>
<td>0.86</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Language</td>
<td>4</td>
<td>0.74</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>Visibility</td>
<td>4</td>
<td>0.82</td>
<td>0.88</td>
</tr>
<tr>
<td>Self-Concept</td>
<td>Action</td>
<td>10</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Language</td>
<td>5</td>
<td>0.88</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Visibility</td>
<td>4</td>
<td>0.87</td>
<td>0.91</td>
</tr>
</tbody>
</table>

2.3. Procedure

The study was conducted in a design with a pre-test, post-test, and follow-up (Figure 1). During the first session, the students answered questions about themselves, such as their age, gender, their usage of media, and the availability of different types of media at home. Furthermore, they answered a questionnaire on their self-concept on possible learning barriers in experimental instructions (SCEI, measurement 1) regarding visibility, language, and action [12].

About a week after the pre-test, the students worked in the learning environment. This was structured in such a way that they first received basic information about magnetism and worked through the historical background as described above. This was followed by two hands-on experiments. After the experiments, the students were asked about their perceived accessibility of the experimental instructions (ACEI) for both of the experiments they had just completed. After the two experiments were conducted, the results were summarized. The students could elect to have a summary sent to them as a PDF file with their results, answers, important background information regarding the experiments, and the summary.

About three weeks after working with the learning environment, a follow-up session concluded the surveys. During this follow-up session, the students once again answered the questions on their self-concept on engaging with experimental instructions (SCEI, measurement 2) regarding the three types of learning barriers.
Figure 1. Design of the study: pre–post-tests with intervention.

3. Results

All statistical analyses were conducted with SPSS 27. For effect size measures, we used $\eta^2_p$ interpreting values from 0.01 to <0.06 as small effects, values from 0.06 to <0.14 as medium effects, and values from 0.14 as large effects [52].

First, we examined the scales used for internal consistency with the help of reliability analyses (Table 1). Most showed acceptable to excellent reliability.

For both the accessibility of experimental instructions (ACEI) and self-concept in engaging with experimental instructions (SCEI) scales, we first examined the total sample for possible effects. To obtain a more accurate picture of the subgroups (gender, school type, and grade level) and dimensions (action, language, and visibility), we then calculated three repeated measures MANOVAs for each dimension, with the dimension as the repetition factor (within) and the subgroups as the between factors. We carried out this procedure because there are gender effects in relation to science [13–15], and effects for the school types were also proven in Germany [53,54] (e.g., PISA). For example, the reading ability is generally higher at academic-track schools than at non-academic-track schools [53,54], and reading ability in turn is related to scientific literacy [55].

3.1. Perception of Accessibility of Experimental Instructions

Overall, the accessibility of the experimental instructions within the learning environment was perceived as being accessible to very accessible ($2.44 \leq M \leq 2.57$, on a scale ranging from 0–3). Figure 2 shows the descriptive values for the three dimensions of accessibility of the instructions for experiment 1 and experiment 2.

To estimate the overall difference between the first and second measurement of accessibility, we conducted a MANOVA with repeated measurements with the overall data. In this analysis, experiments 1 and 2 were used as the repeated measurement factor (within factor) for accessibility and the dimension (action, language, and visibility) as the dependent variables. In this analysis, we focused on possible differences between the two experiments. Hence, only this main effect was of interest and showed a significant main effect for the repetition factor of the experiment ($F(1, 319) = 32.88, p > 0.001, \eta^2_p = 0.09$). This indicates a significant difference between the perceived accessibility of the instructions for experiments 1 and 2. Figure 2 shows that the accessibility was perceived to be higher for the instructions to experiment 2 than to experiment 1.
First, we looked at the accessibility dimension action (descriptive values: Table 2) and conducted three ANOVAs with repeated measures, one for each between factor of gender, school track, and grade level. Within the repeated measures ANOVA with gender as the between factor, there was a significant main effect for the repetition factor experiment \(F(1, 291) = 33.14, p < 0.001, \eta^2_p = 0.102\). However, there was no significant effect for gender \(F(1, 291) = 0.46, p = 0.497, \eta^2_p = 0.002\) or the interaction of experiment and gender \(F(1, 291) = 0.053, p = 0.467, \eta^2_p = 0.002\).

**Table 2.** Descriptive values of the accessibility of the instructions to experiments 1 and 2.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Action</th>
<th>Language</th>
<th>Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>2.44</td>
<td>0.57</td>
<td>2.41</td>
</tr>
<tr>
<td>Boys</td>
<td>2.47</td>
<td>0.53</td>
<td>2.49</td>
</tr>
<tr>
<td>School</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academic</td>
<td>2.71</td>
<td>0.44</td>
<td>2.67</td>
</tr>
<tr>
<td>Non-academic</td>
<td>2.41</td>
<td>0.64</td>
<td>2.45</td>
</tr>
<tr>
<td>Grade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.50</td>
<td>0.56</td>
<td>2.49</td>
</tr>
<tr>
<td>6</td>
<td>2.42</td>
<td>0.54</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Note. The accessibility scales ranged between 0 (= not accessible at all) and 3 (= very accessible).

Within the repeated measures ANOVA, with school track as the between factor, there were two significant main effects, one for the experiment \(F(1, 296) = 34.09, p < 0.001, \eta^2_p = 0.103\), and one for the attended school track \(F(1, 296) = 50.79, p < 0.001, \eta^2_p = 0.146\). However, there was no significant effect for the interaction of experiment and attended school track \(F(1, 296) = 0.04, p = 0.838, \eta^2_p = 0.000\).

Within the repeated measures ANOVA, with grade as the between factor, there was one significant main effect for the repetition factor experiment \(F(1, 291) = 33.50, p < 0.001, \eta^2_p = 0.103\) but none for grade \(F(1, 291) = 2.67, p = 0.104, \eta^2_p = 0.009\) nor for the interaction of experiment and grade \(F(1, 291) = 0.43, p = 0.512, \eta^2_p = 0.001\).

This shows that for the accessibility dimension, all three analyses revealed significant differences between experiments 1 and 2, in which experiment 2 was perceived as being more accessible than experiment 1. As a between factor, only the attended school track was of significant effect. Here, students from the academic track perceived both experimental instructions as being more accessible.
3.1.2. Dimension: Language

Within the repeated measures ANOVA, with gender as the between factor, there was a significant main effect for the experiment \((F(1, 291) = 30.54, p < 0.001, \eta^2_p = 0.095)\). However, there was no significant effect for gender \((F(1, 291) = 2.73, p = 0.100, \eta^2_p = 0.009)\) nor for interaction of experiment and gender \((F(1, 291) = 1.21, p = 0.273, \eta^2_p = 0.004)\).

Within the repeated measures ANOVA, with school track as the between factor, we found two main effects: one for the experiment \((F(1, 296) = 30.51, p < 0.001, \eta^2_p = 0.093)\) and one for the school track \((F(1, 296) = 40.74, p < 0.001, \eta^2_p = 0.121)\). There was no effect for the interaction of experiment and school track \((F(1, 296) = 2.81, p = 0.094, \eta^2_p = 0.009)\).

Within the repeated measures ANOVA, with grade as the between factor, again, there was a main effect for experiment \((F(1, 291) = 31.65, p < 0.001, \eta^2_p = 0.098)\), but none for grade \((F(1, 291) = 2.12, p = 0.147, \eta^2_p = 0.007)\) or the interaction of experiment and grade \((F(1, 291) = 1.88, p = 0.171, \eta^2_p = 0.006)\).

So again, we found significant main effects in each analysis for the repetition factor of the experiment, indicating that the students perceived the instructions to experiment 2 as being more accessible within the dimension of language than the instructions for experiment 1. Moreover, the main effect for school track was significant too, showing that students from the academic school track perceived both experimental instructions regarding language more accessible that students from the non-academic school track. There was no effect regarding gender or grade.

3.1.3. Dimension: Visibility

Next, we looked at the dimension of visibility and analyzed the three between factors gender, school track, and grade level.

The repeated measures ANOVA, with gender as the between factor, revealed no significant effect, neither for the repetition factor of the experiment \((F(1, 291) = 1.86, p = 0.174, \eta^2_p = 0.006)\), nor for gender \((F(1, 291) = 1.15, p = 0.285, \eta^2_p = 0.004)\), or for the interaction of experiment and gender \((F(1, 291) = 0.03, p = 0.872, \eta^2_p = 0.000)\).

Within the repeated measures ANOVA, with school track as the between factor, we found one significant main effect for school tracks \((F(1, 296) = 29.26, p < 0.001, \eta^2_p = 0.090)\). However, there was no significant main effect for the experiment \((F(1, 296) = 1.98, p = 0.160, \eta^2_p = 0.007)\) or for the interaction of experiment and school track \((F(1, 296) = 2.35, p = 0.126, \eta^2_p = 0.008)\).

Regarding the repeated measures ANOVA, with gender as the between factor, there was a significant main effect for grade \((F(1, 291) = 4.64, p = 0.32, \eta^2_p = 0.016)\). But there was neither a significant effect for experiment \((F(1, 291) = 1.84, p = 0.77, \eta^2_p = 0.006)\) nor for the interaction of experiment and grade \((F(1, 291) = 0.00, p = 0.960, \eta^2_p = 0.000)\).

Hence, for the dimension of visibility within the accessibility of the experimental instructions there were two main effects: one for grade and one for school track. This indicates that the experimental instructions were perceived as being more accessible regarding visibility by students in Grade 5 and those from academic-track schools.

3.2. Development of the Ability Self-Concept in Engaging with Experimental Instructions

To estimate the overall difference between the first and second measurements of self-concept in engaging with experimental instructions, we conducted a MANOVA with repeated measurements with the overall data. In this analysis, the first and second measurements of self-concept were used as the repeated measurement factor (within factor) and the dimension (action, language, and visibility) as the dependent variables. In this analysis, we focused on possible differences between the measurements before and after the intervention. Hence, only this effect was of interest and showed a significant main effect for the repetition factor of the experiment \((F(1, 302) = 9.87, p = 0.002, \eta^2_p = 0.032)\). This indicates a significant difference between the two measurements of self-concept in engaging with experimental instructions. Figure 3 shows that self-concept in engaging with experimental instructions (SCEI) was perceived higher after the intervention than
before the intervention. To differentiate between the subgroups and dimensions, we then calculated three repeated measures MANOVAs for each dimension, with the dimension as the repetition factor (within) and the subgroups as the between factors (descriptives: Table 3).

![Figure 3. Development of self-concept in engaging with experimental instructions (SCEI) in three dimensions of ability (language, action, and visual). Scale ranging from 0–3. N = 320 (total sample).](image.png)

Table 3. Descriptive values of the self-concept in engaging with experimental instruction for first (pre-test) and second (follow-up) measurements.

<table>
<thead>
<tr>
<th>n</th>
<th>Gender</th>
<th>Action M</th>
<th>Action SD</th>
<th>Language M</th>
<th>Language SD</th>
<th>Visibility M</th>
<th>Visibility SD</th>
<th>Pre-test</th>
<th>Follow-up</th>
<th>Pre-test</th>
<th>Follow-up</th>
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<tbody>
<tr>
<td>Gender</td>
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<td>0.51</td>
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<tr>
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<td>2.35</td>
<td>0.59</td>
<td>2.2</td>
<td>0.5</td>
<td>2.24</td>
<td>0.47</td>
<td>2.42</td>
<td>0.62</td>
<td>2.33</td>
<td>0.59</td>
<td>2.38</td>
</tr>
<tr>
<td>School</td>
<td>Academic</td>
<td>140</td>
<td>2.40</td>
<td>0.43</td>
<td>2.36</td>
<td>0.39</td>
<td>2.41</td>
<td>0.56</td>
<td>2.53</td>
<td>0.40</td>
<td>2.48</td>
<td>0.40</td>
<td>2.48</td>
</tr>
<tr>
<td></td>
<td>Non-acad.</td>
<td>163</td>
<td>2.13</td>
<td>0.53</td>
<td>2.06</td>
<td>0.54</td>
<td>2.32</td>
<td>0.56</td>
<td>2.23</td>
<td>0.60</td>
<td>2.13</td>
<td>0.63</td>
<td>2.33</td>
</tr>
<tr>
<td>Grade</td>
<td>5</td>
<td>135</td>
<td>2.27</td>
<td>0.45</td>
<td>2.24</td>
<td>0.44</td>
<td>2.43</td>
<td>0.56</td>
<td>2.43</td>
<td>0.52</td>
<td>2.34</td>
<td>0.54</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>162</td>
<td>2.23</td>
<td>0.48</td>
<td>2.18</td>
<td>0.54</td>
<td>2.31</td>
<td>0.56</td>
<td>2.32</td>
<td>0.55</td>
<td>2.27</td>
<td>0.59</td>
<td>2.34</td>
</tr>
</tbody>
</table>

3.2.1. Dimension: Action

The repeated measures ANOVA, with gender as the between factor, showed that none of the three effects was significant: neither the time of measurement ($F(1, 295) = 1.50$, $p = 0.221, \eta^2_p = 0.005$), nor gender ($F(1, 295) = 0.00$, $p = 0.994, \eta^2_p = 0.000$), or the interaction of measurement and gender ($F(1, 295) = 0.52$, $p = 0.471, \eta^2_p = 0.002$).

The repeated measures ANOVA, with the attended school track as the between factor, found that the effects for the time of measurement ($F(1, 301) = 15.10$, $p < 0.001, \eta^2_p = 0.048$) and for school track ($F(1, 301) = 38.24$, $p < 0.001, \eta^2_p = 0.113$) were significant but not the interaction of time of measurement and school track ($F(1, 301) = 0.48$, $p = 0.488, \eta^2_p = 0.002$).

The repeated measures ANOVA, with grade as the between factor, the effect for time of measurement was significant ($F(1, 295) = 16.29$, $p < 0.001, \eta^2_p = 0.052$) but not for grade ($F(1, 295) = 2.07$, $p = 0.152, \eta^2_p = 0.007$) and not for the interaction of time of measurement and grade ($F(1, 295) = 1.53$, $p = 0.217, \eta^2_p = 0.005$).

Hence, this shows that the self-concept in engaging with experimental instructions within the dimension of action developed from the first to second measurement and that this self-concept was higher in general in students from the academic-track schools than students from the non-academic-track schools. The analyses showed no differential effect on self-concept over time concerning gender, school track, and grade.
3.2.2. Dimension: Language

Within the repeated measures ANOVA, with gender as the between factor, the effect from the first to second measurement was significant ($F(1, 295) = 8.36, p = 0.004, \eta^2_p = 0.028$). However, the effect for gender ($F(1, 295) = 0.20, p = 0.657, \eta^2_p = 0.001$) and the interaction of measurement and gender ($F(1, 295) = 1.05, p = 0.307, \eta^2_p = 0.004$) were not significant.

Within the repeated measures ANOVA, with school track as the between factor, we found a significant effect for the time of measurement ($F(1, 301) = 8.93, p < 0.001, \eta^2_p = 0.130$). However, the interaction of measurement and school was not significant ($F(1, 301) = 0.47, p = 0.495, \eta^2_p = 0.002$).

Within the repeated measures ANOVA, with grade as the between factor, again, the time of measurement was significant ($F(1, 295) = 8.43, p = 0.004, \eta^2_p = 0.028$) but not the grade level ($F(1, 295) = 1.52, p = 0.219, \eta^2_p = 0.005$) nor the interaction of measurement and grade level ($F(1, 295) = 0.01, p = 0.911, \eta^2_p = 0.000$).

Altogether, this reveals three significant main effects for the time of measurement, indicating a rise in the self-concept when engaging with experimental instructions and a higher self-concept in engaging with experimental instructions in academic-track students and those in Grade 5 when compared to non-academic-track students and those in Grade 6, respectively.

3.2.3. Dimension: Visibility

Within the repeated measures ANOVA, with gender as the between factor, we found one significant effect for the time of measurement ($F(1, 295) = 15.38, p < 0.001, \eta^2_p = 0.050$). However, there was no significant effect regarding gender ($F(1, 295) = 0.02, p = 0.894, \eta^2_p = 0.000$) or the interaction of measurement and gender ($F(1, 295) = 0.32, p = 0.573, \eta^2_p = 0.001$).

Within the repeated measures ANOVA, with school track as the between factor, only the main effect of school track was significant ($F(1, 301) = 4.36, p = 0.038, \eta^2_p = 0.014$) but not the time of measurement ($F(1, 301) = 1.20, p = 0.275, \eta^2_p = 0.004$) or the interaction of measurement and school track ($F(1, 301) = 0.79, p = 0.376, \eta^2_p = 0.003$).

Within the repeated measures ANOVA, with gender as the between factor, only the main effect for grade level was significant ($F(1, 295) = 5.60, p = 0.019, \eta^2_p = 0.019$). There was no significant effect for the time of measurement ($F(1, 295) = 1.64, p = 0.201, \eta^2_p = 0.006$) or for the interaction of measurement and grade level ($F(1, 295) = 0.29, p = 0.588, \eta^2_p = 0.001$).

Regarding the development of the self-concept within the dimension of visibility, we found that the main effects of grade level and school track were significant, indicating again that pupils attending the academic-track schools perceived their self-concept in engaging with experimental instructions as being higher than students from non-academic-track schools, and that fifth-graders rated their self-concept higher than sixth-graders. The results in relation to the time of measurement are not clear in the visibility dimension, as only one of the three possible main effects was significant. Descriptively, there is a positive development here, but this was only significant for the gender-related analysis.

Table 4 summarizes the effect sizes found during the data analysis. This shows that the time of measurement and the attended school track have an influence on both accessibility and the development of the self-concept for the dimensions of action and language. Students’ gender or grade level generally had no significant influence. As we found no significant interactions between the development of self-concept and gender, the assumption that boys and girls develop in the same way can be maintained. We therefore consider Hypothesis 4, that the self-concept of girls increases to the same extent as that of boys, to be confirmed. It can also be seen that the level of self-concept in engaging with experimental instructions was mainly influenced by the track of the school, favoring students at academic-track schools. The table also shows that the self-concept measured here has developed over time, particularly in the dimensions of action and language.
Table 4. Summary of effects of ANOVAs for the accessibility of experimental instructions and development of the self-concept in engaging with the experimental instruction.

<table>
<thead>
<tr>
<th>Effects</th>
<th>Accessibility</th>
<th>Self-Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Action</td>
<td>Language</td>
</tr>
<tr>
<td>Main</td>
<td>m/m/m</td>
<td>m/m/m</td>
</tr>
<tr>
<td>Gender</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>School track</td>
<td>large</td>
<td>med</td>
</tr>
<tr>
<td>Grade</td>
<td>--</td>
<td>weak</td>
</tr>
<tr>
<td>Interaction with</td>
<td>Gender</td>
<td>--</td>
</tr>
<tr>
<td>measurement</td>
<td>School track</td>
<td>--</td>
</tr>
<tr>
<td>Grade</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Note. For the main effect “measurement”, the first value shows the effect size regarding gender, the second regarding school track, and the third value is for grade. For effect size measures, we used $\eta^2_p$ qualifying values 0.01 up to 0.06 as a weak effect (w), values between 0.06 and 0.13 as a medium effect (m), and values > 0.13 as a large effect [37]. -- indicates that no effect was found.

3.3. Influence of the Accessibility on the Development of the Self-Concept

To gain knowledge on how the perceived accessibility influenced the development of students’ self-concepts, we conducted three linear regression analyses, one for each dimension. Our hypotheses were on how the perceived accessibility influenced the development of students’ self-concepts, with the assumption that higher accessibility rates lead to a stronger development of the self-concept. Therefore, the predictor was the average perceived accessibility ($M$) of both experiments (E1, E2; descriptive values: Table 5). The dependent variable was the development of perceived self-concept in engaging with experimental instructions ($\delta$, descriptive values: Table 5). The development of self-concept in relation to experimental instructions was calculated by subtracting the value of the first measurement from the value of the second measurement. Positive values therefore represent an increase in self-concept, while negative values correspond to a decrease in self-concept.

Table 5. Descriptive values of accessibility and the development of self-concept ($\delta$).

<table>
<thead>
<tr>
<th>N</th>
<th>Action</th>
<th>Language</th>
<th>Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>2.52</td>
<td>2.52</td>
<td>2.58</td>
</tr>
<tr>
<td>SD</td>
<td>0.51</td>
<td>0.55</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 6 shows the results of the three regression analyses, one for each dimension (action, language, and visibility). There were significant effects for all analyses; however, the explained variance ($R^2/corr. R^2$) showed a weak to medium effect [56]. This shows that the accessibility of the experimental instructions had a positive influence; however, it was smaller than expected. Hence, there may be other influences, which is why we conducted three more multiple regression analyses with more predictors.
### Table 6. Results of three linear regression analyses: accessibility on development of self-concept.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>b</th>
<th>SE</th>
<th>beta</th>
<th>t</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action</td>
<td>0.26</td>
<td>0.04</td>
<td>6.22</td>
<td>&lt;0.001</td>
<td>0.18</td>
<td>0.34</td>
</tr>
<tr>
<td>Language</td>
<td>0.27</td>
<td>0.06</td>
<td>0.27</td>
<td>4.58</td>
<td>&lt;0.001</td>
<td>0.39</td>
</tr>
<tr>
<td>Visibility</td>
<td>0.27</td>
<td>0.06</td>
<td>0.27</td>
<td>4.41</td>
<td>&lt;0.001</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Notes. Action: N = 260; R² = 0.08; corr. R² = 0.07; (F(1, 258) = 20.99, p < 0.001. Language: N = 260; R² = 0.07; corr. R² = 0.07; (F(1, 258) = 19.44, p < 0.001. Visibility: N = 260; R² = 0.03; corr. R² = 0.03; (F(1, 258) = 8.17, p = 0.005.

### 3.4. Influences on the Self-Concept with Experimental Instructions

To examine the influence on the development of the self-concept in engaging with the experimental instructions in more detail, a total of three additional multiple regressions were calculated, again, one for each dimension. This time, we wanted to find out exploratively whether there are other factors that affect the self-concept in engaging with experimental instructions. The dependent variable was, again, the value of the self-concept of the respective dimension at the second measurement, i.e., after the intervention. The predictors were the three self-concepts in engaging with experimental instructions at the first measurement point (session 1 = S1), the average perceived accessibility of the two experiments, as well as the school track, gender, and grade level. As this was an exploratory analysis, we used the backwards method [57]. Within the tables (Tables 7–9) for the three multiple regression analyses, only the final model is reported, respectively.

#### Table 7. Multiple regression on self-concept in engaging with experimental instructions (dimension: action) at measurement point 2.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>b</th>
<th>SE</th>
<th>beta</th>
<th>t</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.74</td>
<td>0.15</td>
<td>11.42</td>
<td>&lt;0.001</td>
<td>1.44</td>
<td>2.03</td>
</tr>
<tr>
<td>Accessibility language</td>
<td>0.25</td>
<td>0.07</td>
<td>0.26</td>
<td>3.58</td>
<td>&lt;0.001</td>
<td>0.39</td>
</tr>
<tr>
<td>Accessibility visibility</td>
<td>0.24</td>
<td>0.07</td>
<td>0.24</td>
<td>3.52</td>
<td>&lt;0.001</td>
<td>0.37</td>
</tr>
<tr>
<td>Self-concept action S1</td>
<td>0.39</td>
<td>0.06</td>
<td>0.32</td>
<td>6.24</td>
<td>&lt;0.001</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Notes. N = 260; R² = 0.421; corr. R² = 0.415; (F(3, 256) = 62.15, p < 0.001. Method: backward. Model 7 as final model with three remaining predictors.

#### Table 8. Multiple regression on self-concept in engaging with experimental instructions (dimension: language) at measurement point 2.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>b</th>
<th>SE</th>
<th>beta</th>
<th>t</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.71</td>
<td>0.17</td>
<td>10.13</td>
<td>&lt;0.001</td>
<td>1.38</td>
<td>2.05</td>
</tr>
<tr>
<td>Accessibility language</td>
<td>0.40</td>
<td>0.07</td>
<td>0.40</td>
<td>0.48</td>
<td>&lt;0.001</td>
<td>0.54</td>
</tr>
<tr>
<td>Accessibility visibility</td>
<td>0.14</td>
<td>0.07</td>
<td>0.13</td>
<td>1.96</td>
<td>0.051</td>
<td>0.27</td>
</tr>
<tr>
<td>Self-concept action S1</td>
<td>0.25</td>
<td>0.08</td>
<td>0.20</td>
<td>3.31</td>
<td>0.001</td>
<td>0.10</td>
</tr>
<tr>
<td>Self-concept language S1</td>
<td>0.13</td>
<td>0.07</td>
<td>0.11</td>
<td>1.81</td>
<td>0.071</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Notes. N = 260; R² = 0.447; corr. R² = 0.439; (F(4, 255) = 51.59, p < 0.001. Method: backward. Model 6 as final model with four remaining predictors.

Table 10 gives an overview of the identified predictors for each multiple regression analysis above (results of Tables 7–9). Table 10 indicates that for the value of the second measurement of self-concept in engaging with experimental instructions, each self-concept’s value at the first measurement had an influence. Additionally, the accessibility to visibility for all three analyses predicted all three self-concepts on the second measurement. However,
the accessibility language had an influence on the second self-concept within the dimensions of action and language.

Table 9. Multiple regression on self-concept in engaging with experimental instructions (dimension: visibility) at measurement point 2.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>b</th>
<th>SE</th>
<th>beta</th>
<th>t</th>
<th>p</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.82</td>
<td>0.15</td>
<td>12.08</td>
<td>&lt;0.001</td>
<td>1.53</td>
<td>2.12</td>
</tr>
<tr>
<td>Accessibility visibility</td>
<td>0.39</td>
<td>0.06</td>
<td>0.36</td>
<td>6.49</td>
<td>&lt;0.001</td>
<td>0.51</td>
</tr>
<tr>
<td>Self-concept visibility S1</td>
<td>0.32</td>
<td>0.06</td>
<td>0.30</td>
<td>5.52</td>
<td>&lt;0.001</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Notes. N = 260; R² = 0.278; corr. R² = 0.273; F(2, 257) = 49.52, p < 0.001. Method: backward. Model 8 as final model with two remaining predictors.

Table 10. Overview of predictors in the three multiple regressions on self-concept at measurement point 2.

<table>
<thead>
<tr>
<th></th>
<th>SCEI 1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Action</td>
<td>**</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td></td>
<td>**</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>SCEI 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td></td>
<td>**</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td></td>
<td>**</td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Accessibility</td>
<td></td>
<td>**</td>
<td></td>
<td>**</td>
</tr>
</tbody>
</table>

Note. SCEI: self-concept with experimental instructions. In all three multiple regressions, the predictors gender, school track, and grade level were excluded. *: significant predictor (p < 0.05); **: significant predictor (p < 0.001); -- the predictor was included within the model, but with no significant p-value.

4. Discussion

We conducted a study with 348 students in secondary school to gain insight into how a storytelling- and comic-style digital learning environment can foster scientific literacy, especially experimentation, for all students following accessibility and stereotype-free aspects. The focus was on the development of students’ self-concepts in engaging with experimental instructions, which was measured twice, before and after the intervention with the digital learning environment that included two hands-on experiments on magnetism. During the intervention, we established the perceived accessibility of both experimental instructions as the independent variable.

Our results showed great accessibility of the experimental instructions provided within the digital learning environment. However, we found that the accessibility for the second experiment was even higher than that of the first experiment. The results indicate that experiment 2 was perceived more accessible than experiment 1. This could be due to training effects because of the repeated experimental process, or experiment 2 (with euro coins) being more familiar to the students than experiment 1 (with materials such as screws, metal plates, or test tubes). However, the descriptive values indicate a high accessibility for both experiments. Moreover, we observed differences in the perceived accessibility between students at different school tracks. A better accessibility was perceived by academic-track students than by students of other tracks. This might be a similar effect to reading, where various studies repeatedly showed that students with an academic background had better reading skills than students without an academic background. Although we had designed a low-barrier digital learning environment, we found differences in the perception of accessibility. This might be due to different reading skills, but this aspect would require further empirical research in the future.

Altogether, our hypothesis regarding accessibility was confirmed by the overall high values indicating a high accessibility of the experimental instructions and the absence of
learning barriers. With our study, we were able to create a digital learning environment to foster scientific literacy that was accessible to the participating students in secondary school in Grades 5 and 6.

Regarding the self-concept in engaging with experimental instructions, there was an increase from the first to second measurement, confirming our second hypothesis. Our digital learning environment had a positive impact on the self-concept in engaging with experimental instructions, especially for the dimensions of language and action. This could be attributed to the design of our digital learning environment, which applied comics and incorporated stereotype-free elements and a clearly visible structure based on the research cycle. Furthermore, we assumed a training effect during the learning environment. We enclosed two experimental instructions that were set up in a similar way and structured by the research cycle. This repetitive procedure may have had a reinforcing effect on the students [61,62], as they followed the procedure, the words of the experimental instructions were similar in both instructions, and they performed similar actions while conducting the experiments. In addition, the experimental instructions were very accessible and therefore comprehensible and understandable for the students, which is why it is assumed that students had no difficulties during the experiments. These two factors, the repetition [62–65] and accessibility, could have led to the increase in self-concept.

Moreover, the results showed that the more accessible the experimental instructions were perceived, the more the self-concept in engaging with experimental instructions increased. This indicates that this type of learning environment, which puts a great emphasis on accessibility, can be helpful for all students and can increase the self-concept in engaging with experimental instructions; hence, Hypothesis 3 was confirmed. These results were strengthened by the exploratory multiple regression analyses, in which the level of the initial self-concept, but also the respective dimension of accessibility, played a role when all other factors, (e.g., gender, school track, or class level) were excluded. However, accessibility in relation to visibility seemed to play a role, as the visibility dimensions of accessibility were also still present in the respective final models of the multiple regressions. Hence, the initial self-concept in dealing with experimental instructions, especially on the dimension of action, and the accessibility on the dimension of visibility seem to be strong prerequisites for the development of the self-concept in engaging with experimental instructions.

Moreover, the stereotype-free design of the learning environment and the accessibility of the experimental instructions seemed to foster both boys and girls. We found that the self-concept in engaging with experimental instructions developed equally for boys and girls. Since previous empirical studies found girls to have a less pronounced self-concept in the natural sciences [13,14], the result of our study shows promise for promoting girls’ interest and self-concept in the sciences.

The results of the present study highlight that magnetism as a topic of science education can effectively be supported by accessible digital learning environments and can be communicated in a motivating way. Digital learning environments are thus an accessible tool to introduce basic concepts of scientific literacy in a way that students can conduct experiments independently.

Limitations and Future Directions

Despite the potential of our study, these results can only be a first hint at the influences of a deliberately low-barrier and digital learning environment as stereotype free as possible. First, there was an influence of accessibility on the development of the self-concept in engaging with experimental instructions in the absence of other factors. However, this became less pronounced when the initial self-concept was added. Here, it became clear that the self-concept action had a broad influence. Therefore, the assumption that self-concept can be strengthened by a low-barrier and stereotype-free learning environment was confirmed. However, the assumption that self-concept can be strengthened by accessibility is tenable but would have to be investigated in the long term with repeated interventions in order to confirm the assumption.
Second, it remains to be seen whether other factors, such as general media consumption, familiarity with digital media, or socio-economic status, may have an impact on the development of the self-concept in engaging with digital experimental instructions. In addition, we refer here to students’ self-assessments of perceived accessibility and self-concepts. This could be corroborated by other measures, such as cognitive load or motivation. Third, it remains to be seen whether only the positive development of the self-concept or also the accessibility of the learning environment has an impact on learning performance both in the short and long term. Hence, a more objective knowledge test should be included in a pre–post-test design to include further neutral measures of change in addition to the more subjective self-assessment and thus gain a better insight into the learning processes. Moreover, we included three sessions. However, we have no measure to validate the long-term effects or a measure of repeated interventions, (e.g., with different topics) to strengthen the effects found here. These are issues and open research questions that should be targeted and empirically investigated in the future to further validate the use of such digital learning environments.

5. Conclusions

The present study showed that the newly developed digital learning environment was perceived as low in learning barriers regarding the experimental instructions. With our study design, we were able to raise the self-concept of secondary school students in engaging with experimental instructions from the first to second measurement. There was no difference in the perception of the accessibility and self-concept regarding gender. This is good news, as it shows that all students participating in our study perceived the experimental instructions as accessible, and the self-concept of all students was increased. However, we saw an advantage for students at academic-track schools regarding accessibility and self-concept in engaging with experimental instructions. Thus, further research is needed, as our emphasis was on fostering the experience of all students, especially focusing on low achievers in general and giving them an opportunity to participate in science classes.

Despite this, there is no doubt that learning environments focusing on low learning barriers and stereotype-free aspects enable students to complete tasks independently and foster their self-concept regarding experimental instructions. This, in turn, provides teachers with the time and space in their lessons during which they can devote special attention to individual students and either encourage them further or support them with additional tasks. In this way, both high- and low-achieving students can be supported in the classroom. This will not only promote students’ self-concepts, but also strengthen the individual support provided by teachers in the classroom. Furthermore, the participation of all students can be fostered and enable students to engage in participatory debates [4] in scientific issues.

In addition, the absence of gender effects in the learning environment designed in our study is significant for the promotion of gender equality in STEM fields. Given the shortage of qualified professionals in the STEM sector, both in Germany and other industrialized countries, it is crucial to harness the potential and willingness of young men and especially women [16–21]. We simply cannot afford to inhibit the interest and motivation of young girls in secondary education to make them choose alternative career paths [18,19]. Therefore, it is important to create inclusive and supportive learning environments in STEM education to encourage girls to pursue careers in these fields and to realize their full potential. In doing so, we can work toward closing the gender gap in STEM professions and promoting a more equitable society in which everyone can participate at their best.

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