education sciences

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Plant Identification in the 21st Century—What Possibilities Do Modern Identification Keys Offer for Biology Lessons?

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Abstract: The loss of biodiversity and the accompanying "plant blindness" are major problems for mankind. Biology classes in Germany deal with this topic with the aim of enabling students to identify plants in their surroundings. Here, the process of plant identification plays a key role. To render the process of plant identification, more student-oriented, new digital approaches are being developed. Thus, teachers are now being confronted with digital tools for plant identification without having exact knowledge of their added value. This intervention study was therefore conducted in order to determine the effects on learning by means of a paper-based dichotomous identification key (Eikes Baumschule) and a digital identification app (ID-Logics). The results show that both tools have individual media-related differences that should be considered when designing learning strategies: With the previously reduced, paper-based tool, students can identify plants more quickly and often more correctly. However, the digital app has advantages in terms of enjoyment and learning about individual characteristics of plants. The study shows the challenges and opportunities associated with the (digital) medium. Furthermore, it sheds light on the process of species determination and reveals further fields of research in science education.

Keywords: media in education; mobile learning; teaching/learning strategies; species identification

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Citation: Finger, A.; Groß, J.; Zabel, J. Plant Identification in the 21st Century—What Possibilities Do Modern Identification Keys Offer for Biology Lessons? *Educ. Sci.* **2022**, *12*, 849. https://doi.org/10.3390/educsci12120849

Academic Editors: Jian-Hong Ye, Yung-Wei Hao, Yu-Feng Wu and Savvas A. Chatzichristofis

Received: 24 October 2022
Accepted: 15 November 2022
Published: 23 November 2022

1. Introduction

The loss of biodiversity is one of the biggest challenges of the 21st century [1]. But it seems that this problem is not a priority in the public eye. This low awareness can partially be explained by the lack of species knowledge in society. Whereas large animal species are still in the focus of social perception, the decline in inconspicuous animal species is hardly registered. Empirical studies show that knowledge and interest about plants is anything other than widespread. This phenomenon is called "plant blindness" [2]. Studies have shown that this problem has been increasing in recent years [3,4]. Numerous studies have attempted to combat plant blindness by investigating and developing new methods for improving plant knowledge in schools, e.g., [5,6]. These studies have shown that young students have a poor or very limited knowledge of species, and that conveying or improving this knowledge is a difficult task for educators.

One recent hope for motivating students to take more interest in plants and their identification lies in the development and use of digital identification tools. Many scientists are advocating the digital approach towards the identification of plants, since they expect an easier accessibility as well as better learning outcomes [7–9]. But only few empirical studies have so far analysed the effects of digital identification tools on students. Stagg and Donkin [10] conducted a comparison study in the United Kingdom using the usability concept, in order to test the effectiveness of printed identification keys versus digital multi-access keys. The results of the study were inconclusive as to which key was more usable. But they also speculated that younger students may show a stronger preference for the digital application. Jacquemart [11] tested a digital dichotomous identification key in basic level university courses by creating a distance learning environment. This setting revealed that the digital presentation of plants can be useful for students to practice their identification skills and gather knowledge about plants and their characteristics.

But there is still little known about the impact of digital tools at school level and whether they can improve learning processes. In general, empirical information on the impact of digital media on student learning is limited. So far, digital tools have often been studied under lab conditions and results have been obtained that are difficult to transfer to authentic field trip contexts in schools. Therefore, teachers and professionals know too little about the impact of digital tools, particularly when they are used in authentic learning environments. Nevertheless, they are obliged to use them, since some German federal states such as Saxony-Anhalt included the identification of plants with digital tools in the biology curriculum of the 9th grade [12].

But what potential do modern plant identification keys designed for schools really offer, and how do they support the learning of plant identification and specific plant characteristics? This question remains open in view of the inconclusive results and the few studies available. To answer this question, we investigated the effects of two different identification tools: a digital polytomous key and a reduced paper-based dichotomous key for plant identification. In order to provide an authentic context for our study, data were collected during a school field trip.

2. Theory

2.1. Plant Blindness and Species Knowledge

Bollnow [13] (p. 119) stated: 'We see only those plants for which we have names'. Accordingly, an aspect of plant blindness is a lack of knowledge about plants (species knowledge) and another is the inability to recognise individual plant specimens by means of species identification [14]. In a broader context, the knowledge of species is thus necessary as a basis for understanding biodiversity. Only through species knowledge and the appreciation of biodiversity can problems such as biodiversity loss be recognised by students [15–18]. Hooykaas et al. [19] presented the concept of 'species literacy'—a concept of biodiversity which focuses on species—in order to tackle the loss of biodiversity. Therein, the ability to identify species and thus the understanding of the species concept are described as essential in order to increase people's awareness of biodiversity and species loss. Despite their great significance for life, plants have a very low priority for school children [20,21]. In Germany, for example, the interest of young people in identifying plants and in the subject area of botany halved from 40% to 20% between 1997 and 2003 [22]. International studies also indicate that plants play only a subordinate role in students' interest [23]. Subsequently, it is not surprising that students only have a very rudimentary knowledge of species [24]. Jäkel and Schaer [17] were able to show that primary school students can name less than five species with certainty. Especially in the case of woody plants, great deficits in species knowledge were revealed. Further studies demonstrate that students recognise only a few species in general, such as dandelions and daisies [15,17,24–28]. Tunnicliffe [29] was able to demonstrate that primary school children strive to learn or know the names of the plants presented to them in order to match what they see with their own concepts. The studies from Lindemann-Matthies [30] or Jäkel and Schaer [17] also showed that both interest and species knowledge can be positively influenced by intensive engagement with the subject in school and out-of-school learning situations. Especially out-of-school environments that cannot be replicated in the classroom seem to be an effective way of increasing student interest and engagement in a subject [31]. As has already been shown in other studies on interest in plants, a subject-specific difference between girls and boys exists in this respect [27,32,33]. This gender difference also influences the ability to recognise species. For example, various studies have shown that female students have a better knowledge of plants than male students [30,34,35]. On the one hand, this manifests itself in the general knowledge of species, and on the other, in the ability to recognise them. Suggested possible influencing factors for this difference are a higher interest in animals and plants [15,17] or in biology lessons in general [21], as well as a higher appreciation for plants [35]. It is this literature that roused our interest in the gender-specific effect of the plant identification tools on species learning.

2.2. Identification Tools

Educational researchers have long been looking for opportunities to address the problem of increasing plant blindness in students and to find the corresponding answers. Contact with nature and plants should be encouraged in an early stage of child development, such as in kindergarten and elementary school, e.g., [26]. Interest in plants, however, often diminishes as personal development progresses, as plants and nature do not have a prominent standing in our technically oriented world [23]. One reason for the growing plant blindness among students seems to be that nowadays, students rarely experience nature directly. Instead, digital media usually play a dominant role in students' everyday life. According to the Bitkom study [36], 67% of 10- to 11-year-olds and already 92% of 14- to 15-year-old students own a smartphone. Consequently, it makes sense to address young people through this medium. As a result, many applications and approaches have been developed in recent years for plant identification. Some of these applications use pattern recognition to virtually automatically identify plants based on digital image recognition. Chaki et al. [37] developed a Neuro-fuzzy classifier that uses plant leaves, which proved an 80–100% classification accuracy, depending on the respective species. Sekeroglu and Inan [38] demonstrated that their neural network approach could recognise 97.2% of the 27 leaf types. Often, these programs use images of distinct plant features such as leaves or blossoms to identify a species. All of these popular programmes take pictures and transmit them online to a server for analysis, which performs the identification, so that in the end the species can be identified by the program.

But botanical species expertise in school is not only focused on memorising the correct names of species. Rather, a (blind) dependence on a purely server-based identification should be counteracted. And a competence for a scientifically oriented education should be built up among the students. The main objective here is to train students in one of the oldest skills in biology: the ability for plant identification. For learning and identification in the case of living beings, it is crucial to take students by the hand and train them to identify essential biological characteristics. Through the ability to identify plants, students are encouraged to take a closer look at these, and discover the unique biological characteristics of individual species, which could help reduce the students' plant blindness. Also, enhancing species knowledge is assumed to increase the awareness for biodiversity and its possible loss [19]. Therefore, these identification tools that seem promising and appealing at first sight, and work with an automatic identification algorithm were not considered in this study, since the learning goals do not focus only on the species name. Thus, this study focused on two identification keys specifically designed for school use.

Dichotomous paper-based identification key

Conventional identification tools such as the identification key 'Rothmaler–Excursion Flora of Germany' [39] are built up dichotomously. This means that users must decide between two descriptions of a certain identification character of the plant to move forward in the process. The identification process is predetermined and does not consider season or location. In order to use these tools, students require extensive knowledge about scientific botanical terms, which are used to describe a certain characteristic of a plant and its different appearances. Furthermore, certain characteristics are seasonal and may not be available at the time of the identification process. This may lead to problems and result in the failure of the process, which is accompanied by demotivation and loss of interest. Such identification tools are mostly used by experts and are rarely applicable in schools. To give students an easy access and the ability to determine plants in a specific area, different tools have been developed in recent years. For instance, Feketitsch [40] developed an adaptable dichotomous identification key based on a digital algorithm. This digital identification tool allows teachers and educators to create a printable key before beginning the lesson with a reduced scope of species—specific for the shrubs and trees of a certain area. In order to create a customised printable version for plant identification, an educator can select a subset of species out of a total of 85 shrubs and trees in the tools list from Eikes Baumschule [41]. The identification process is guided and based on the graphical representation of the important characteristics (Figure 1). It reduces the botanical terms and written descriptions of the plant features to a minimum, so that laypersons can easily identify shrubs and trees within a limited spectrum of species. Nevertheless, these advantages (easy access, the limitation of species scope) mean that the tool cannot be used universally in every situation, since a preselection of the species is required.

Polytomous multi-access key

A rather new possibility for identifying plants that opens up from digitisation is the use of polytomous identification keys. The ID-Logics app (INITREE Software GmbH, Berlin, Germany) used in this study was designed and developed specifically for students under consideration of their problems in understanding written descriptions. The digitisation provided developers with new ways of presenting plants and guiding students through the identification process. Here, the dichotomous path was replaced by a polytomous algorithm which presents more than two characteristics of a plant feature to the user in the form of a graphic representation (Figure 1). For previously identified problems with the recognition of plant characteristics, explanatory videos are offered that establish a connection between form and function [42]. In addition, the app possesses a fault tolerance that helps students in the process of identification. In this way, the algorithm of the ID-Logics app can determine the probability of remaining plants and quickly reduce the number of species. Only specific characteristics are presented that usually lead to about 1–6 remaining final species. These species are presented as pictured and illustrated fact sheets to help the students verify the plant in front of them. By using digital media with access to the current date, the season is also taken into consideration for the identification process. Thus, the ID-Logics app only offers features that are available during the particular season.

Similarities and differences between the identification tools

Nowadays, teachers are faced with the question of which tools are suitable for identifying plants, as they can choose from digital and analogue tools. The use of digital tools, for example in plant identification, opens up new possibilities which, according to the SAMR model [43], should go beyond a simple digitisation of an analogue structure, i.e., a simple replacement, in order to offer an added value process (Table 1). For example, a digitally designed tool such as ID-Logics not only enables new approaches towards plant identification, but also presents teachers with new opportunities and challenges in its use. This leads to a redefinition of the learning process [43]. Therefore, the intention of this paper is to investigate the impact of a new digital approach with a similar identification tool. As already mentioned, the digital assessment process cannot be reproduced on paper, so that this attempt also has its limitations. Nevertheless, an attempt was made to ensure a high degree of comparability in the choice of tools. Thus, both keys were developed empirically for the use by students to help identify plants [40,42]. Both tools focus on a graphical representation during the identification process rather than on text-based descriptions. During the development process of both tools, the developers (Affeld & Groß: ID-Logics; Feketitsch & Lehnert: Eikes Baumschule) reported that novices indeed benefit from this approach. But in some aspects, the tools differ: While Eikes Baumschule is a dichotomous, paper-based identification tool that offers a pre-selected species spectrum, the ID-Logics app is a polytomous multi-access key that works with the full range of species (n = 192) on offline digital devices.

Table 1. The SAMR model for assessing the integration of digital technologies in biology education adapted from [43,44].

	Level	Definition	Added Value
Enhancement	Substitution	An analogue medium is digitally offered.	No functional enhancement
	Augmentation	Digital technologies provide improvements (e.g., audio, video and animation).	Low functional extension (e.g., non-linear information access).
Transformation	Modification	Digital technologies bring about fundamental changes in teaching (e.g., cooperative location-independent work with etherpads).	Individualised, cooperative and product-oriented-constructive extension.
	Redefinition	Use of digital technologies enables new forms of teaching (e.g., non-dichotomous identification of plants).	Teaching and learning opportunities that cannot be implemented with analogue media.

2.2.1. Usability of an Identification Key

Identification keys are important tools for laypersons and experts in order to identify species and learn about nature [45]. These keys are also important for estimating biodiversity and, moreover, its loss. In 1992, the Global Biodiversity Assessment stated that 'The range of available field guides, keys and other identifying aids is a major constraint to the assessment of biodiversity' [46] (p. 568). To study biodiversity with students despite this constraint, identification keys with high usability should be used. This may motivate students to use these tools in their everyday life as well as enhance their knowledge about nature. The usability concept was defined by Lawrence and Norrish [47] with three parameters: efficiency, satisfaction and effectiveness. Efficiency is the minimised time and effort required to identify a plant. Satisfaction is the enjoyment of using the guide. Effectiveness is the ability of a user to make a successful identification. Since success is not the only parameter for effectiveness in school, the concept was expanded in this study to include species knowledge and characteristics learning.

2.2.2. Characteristics Learning—The 'Leaf or Leaflet' Problem

The study from Affeldt, Groß and Stahl [48] showed that students can generally identify several tree characters, but tend to focus on the description of leaves. The 'leaf or leaflet' case chosen as an example illustrates the following educational challenges: Most of the students' conceptions of leaves differ from the scientific perspective. In the study from Affeldt, Groß and Stahl [48] (teaching experiments, $n = 28$), students described all kinds of leaves as 'green', 'simple in shape' and 'with a stalk'. Botanists also use leaves as a central character to identify trees. In doing so, they distinguish between simple, pinnate or lobed leaves. The ability to differentiate between different types of leaves is a prerequisite for conventional identification tools, but most students have problems in distinguishing between simple leaves and the leaflets of pinnate leaves. The study demonstrated that students were not aware of these differences and interpreted a leaflet as a simple leaf. The authors pointed out that these students used their basic-level concepts of leaves [48]. These concepts reflect our everyday experiences and disregard complex issues of scientific conceptions and therefore, most of the students do not apply the concept of pinnate leaves. As a consequence, in the process of tree identification, students encounter situations in which they need assistance. In the ID-Logics-app, two ways of meeting these challenges were designed: Firstly, interventions with additional information were developed. In case of the 'leaf-or-leaflet' example, an explanatory video was used that explains how to identify a single leaf: 'You can identify a single leaf by looking at the connection of the base of the leaf-stalk to the twig: it broadens and there is a bud directly above it.' (ID-Logics). Secondly, the database was enlarged with regard to the students' perspectives. Trees with pinnate leaves now contain the trait 'simple' in the feature library in the database. Based on these changes, the process of tree identification is more likely to end with the scientifically correct naming of the species. In contrast to traditional identification tools, the diversity of features and the quantity of identification steps during the process were reduced. Hence, a programmatic logic with multifactorial reduction in characters was designed, which uses information about the remaining species and available features. Eikes Baumschule also aims at taking the pupils' concepts into account in the identification key. Similar to the ID-Logics app, it uses mainly symbolic representations of plant features. However, to overcome misconceptions in the identification process, it rather relies on the teacher. In the identification key, only graphic accents such as a red outline of features are offered.

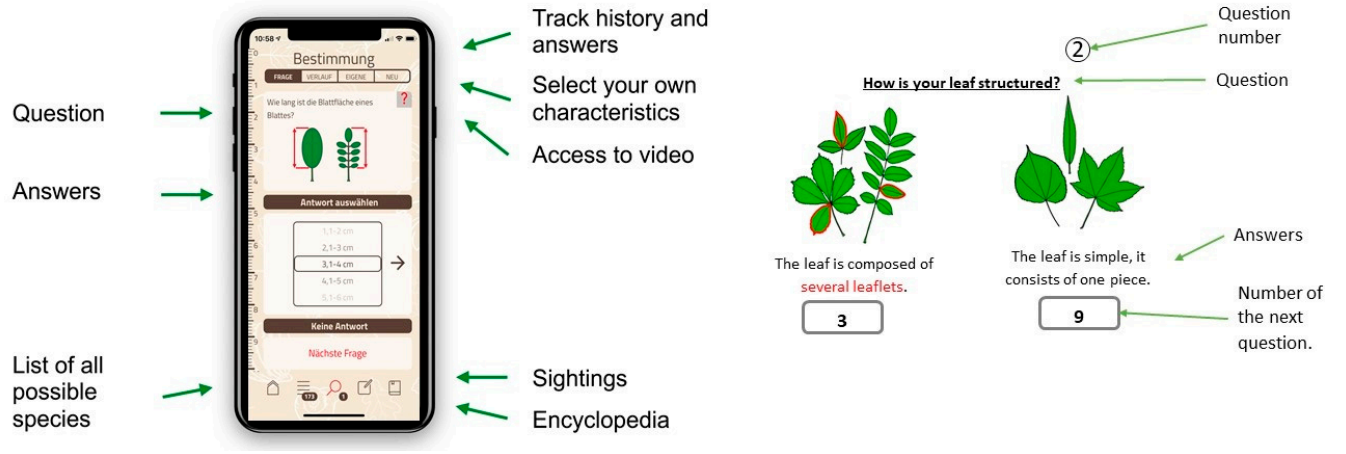

Figure 1. The app ID-Logics (**left**) [49], dichotomous identification key Eikes Baumschule (**right**) [41].

2.3. Research Question and Hypotheses

The central question of the exploratory study was whether modern identification media represent a more effective and efficient approach to the well-known problem of plant blindness. In other words, to what extent does a digital plant identification key help students learn plant identification and specific plant features? In order to empirically investigate this rather broad question, the concept of usability [47] was adopted and the question was divided into several hypotheses.

Hypothesis 1. *Effectiveness of the tool.*

We expect both the polytomous multi-access key (ID-Logics app) and the reduced identification key (paper based) to positively influence the ability to identify plants. Furthermore, the type of identification key also has an influence on the recognition of the leaflet. Female students are expected to remember more species correctly than male students.

H1a. *Due to the visual scaffolding we expect that the ID-Logics app should be more effective than the reduced identification key.*

H1b. *Due to the graphical presentation and the assistance in the ID-Logics app designed to meet learner's needs, we assume that students will learn to recognise morphological features such as the leaflet better with the ID-Logics app.*

H1c. *Female students can remember more species correctly when using the ID-Logics app, due to a higher affinity for plants.*

Hypothesis 2. *Efficiency of the tool.*

The type of plant identification key has an influence on the time required.

H2. *Due to its limited number of species, we assume that the reduced identification key will lead to a quicker identification process.*

Hypothesis 3. *Satisfaction with the tool.*

The type of plant identification key influences the reported enjoyment.

H3. *Due to the graphical presentation, the individual support functions and the general enthusiasm of the students for technology, we assume that the ID-Logics app will achieve a higher level of enjoyment than the reduced identification key.*

3. Materials and Methods

3.1. Participants and Procedure

This experimental study was carried out in collaboration with a high school in Saxony-Anhalt, Germany. The intervention consisted of a one-day field-trip to a meadow with typical shrubs and trees. All students were in the late 9th or early 10th grade and were on average 14–16 years old (M = 14.8, SD = 0.628). The intervention was planned for 310 students from a total of twelve classes. Of these, 283 (52% male, 48% female) took part in the study, spread over four field-trip days.

The respective sample size of the study varies depending on the research design and question and is therefore shown separately in the presentation of the results. Missing values that arose during the research are analysed in the Section 6.

The students were informed about the field-trip 14 days beforehand by the first author and their biology teachers. Prior to the field-trip, the students had received no specific training or preparation for identifying plants. The students went through the normal school curriculum, which focused on plant and species identification in the 7th grade. Since the field-trip was part of the regular biology class, all students were required to participate.

During the field-trip, the students visited eight learning stations that focused on different aspects of the meadow's ecosystem (e.g., water quality, calculation of the flow velocity of the river Saale, soil analysis). Since the field-trip area was located on a small island, the students assembled into groups of 10 people at maximum and walked freely between the stations. To prevent agglomerations at the stations, the groups were advised to move clockwise between the stations. Thus, each station was only visited by one group at a time and no direct interaction between the groups was possible. One of the learning stations was the plant identification station. Here, each student had to identify five previously marked shrubs and tree species. Two of these species possessed compound leaves comprising of leaflets, which the students had to consider during the identification. To evaluate the usability of the assigned tools during the plant identification exercise, an experimental setting was employed. The student groups were randomly assigned to one of two tools (see Figure 2). They either received an iPad with the identification software ID-Logics or a paper-based identification tool derived from Eikes Baumschule (see Section 2.2). The paper tool was designed for the specific area and only included 25 local tree and shrubs species. After assigning the groups to the tools, standardised instructions were given, specific to the tool used. Arriving at a tree, students were asked to write down their assumption of the tree's species name. Thereafter, they commenced the identification process. Each time the students identified a plant, they were asked to note their identification results. The students could decide on the order of the identification process themselves and were allowed to move freely within the plant identification station area. No time limit for the identification process was given. The time the students needed to identify a tree species was recorded by a research assistant who helped with general orientation in the area but was not allowed to intervene during the process. In order to measure their satisfaction, the students were to fill out a questionnaire immediately before and after they entered/left the identification area. The standardised questionnaire focused on intrinsic motivation and contained an enjoyment scale.

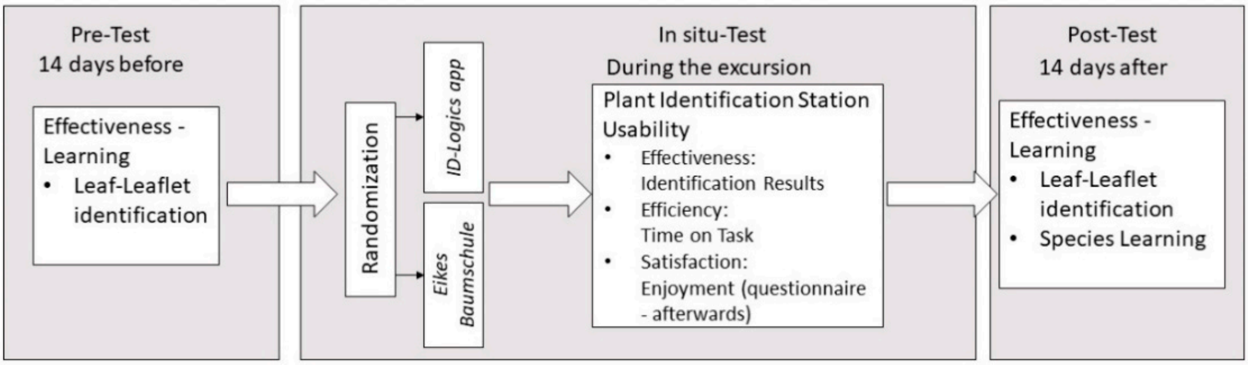

Figure 2. Study design.

3.2. Data Collection

To answer the research question, we determined the following variables: usability, characteristic identification, and species learning. Data were collected before, during and after the field-trip by means of observation as well as via pen-and-paper questionnaires (see Figure 2).

3.2.1. Usability

Students were asked to note their final result after each identification process. To evaluate the usability of the two keys, the effectiveness, efficiency and satisfaction were measured according to Lawrence and Norrish [47]. In order to assess the effectiveness of the identification tools, the students' success rate was determined as the proportion of correctly identified species with scores ranging from 0 to 1.

To measure the efficiency of the identification tools, the time needed for the identification process was recorded. The students' satisfaction with the key was measured using a short questionnaire and the 'enjoyment' scale, provided after the identification procedure. The 'enjoyment' scale was taken from the Intrinsic Motivation Short Scale (SIM), which is based on the theories and templates on intrinsic motivation by Decy and Ryan [50]. The SIM was chosen because it is designed for school situations and has already been translated into German [51]. Studies also showed that the scale 'enjoyment' can be deemed reliable and valid (Table 2). The students were instructed to rate their agreement to the respective statements on a 5-point-Likert-scale (ranging from 1 = I do not agree to 5 = I agree completely). For further information see the results that will be published separately in Finger, Bergmann-Gering and Groß [52].

Table 2. Background information on the used self-report scale 'enjoyment'.

Scale	Items	Example	Origin	Cronbach's α	Based on	Used by
enjoyment	3	I enjoyed identifying species using the identification tool	[50]	0.77	[50,53–55]	[56–58]

3.2.2. Characteristic Identification Test—Leaf or Leaflet

In order to assess if the tools can support the learning of certain plant characteristics, the students' ability to learn and recognise an important characteristic was measured. For this purpose, students were examined 14 days before (pre-test) and 14 days after the field-trip (post-test) (Figure 2). During the test, they were asked to circle a single leaf of each species presented. Of the 4 presented species, only one had the leaflet characteristic, the others had leaves.

3.2.3. Species Learning

To test the effect of the tools on species learning, we evaluated the students' ability to remember the identified plants during the post-test 14 days after the field-trip (Figure 2).

The students were required to write down the five shrubs and trees which had been presented to them during the field-trip. The number of correctly named species (0 to 5) was then recorded for each student.

3.3. Data Analysis

All data analyses were performed with IBM SPSS Statistics for Windows 25.0 (IBM Corp., Armonk, NY, USA). We used different analytical approaches with regard to the respective hypothesis. Assumptions (i.e., no significant outliers, normal distribution of residuals) were checked in the case of all analyses by means of extensive descriptive analyses. Unless explicitly stated in the Section 4, all assumptions were met.

Group-specific differences in effectiveness (rate of successful plant identification), efficiency (time taken) and enjoyment (self-report scale) were each analysed with a One-way Analysis of Variance (ANOVA) with the medium (digital or paper-based) as a fixed effect (H1a, H2, H3).

In order to examine the relation between the medium used and the ability to identify a leaflet before and after the intervention, a repeated-measurement ANOVA was conducted, with time (pre/post intervention) as within-subject factor, medium as between- subject factor, and expected interactions between both factors (H1b).

Differences in the students' ability to learn species names (H1c) were analysed using a two-way ANOVA with gender (male/female) and medium (digital/paper-based), as well as their interaction as fixed effects. The pairwise comparisons of the subgroups for medium and gender were performed using a post hoc test with Bonferroni correction of *p*-values.

4. Results

4.1. Usability

The results on effectiveness revealed a large and statistically significant difference between the tools ($F(1,217) = 56.32$, $p < 0.001$, partial $\eta^2 = 0.206$, Table 3). The efficiency of the tools was determined by recording the individual identification time. It differed statistically significantly with a large effect between the two tools ($F(1,159)= 23.53$, $p < 0.001$, partial $\eta^2 = 0.275$). Students who used the digital tool were engaged in the process for about 6 min longer than the group with the reduced paper-based identification key. The results on enjoyment showed a statistically significant, but small-sized effect between the tools ($F(1,250) = 6.748$, $p < 0.01$, partial $\eta^2 = 0.026$.

Table 3. ANOVA results for average success and efficiency of the plant identification.

Key Characteristic	Variable	Reduced Paper-Based Identification Key		Digital Identification Key (ID-Logics App)		F	*p*	N²	Partial η²
		M¹	SD	M¹	SD				
effectiveness	Proportion of correctly identified species	0.76	0.27	0.49	0.27	56.32	<0.001	218	0.206
efficiency	Total time of species identification [min]	18.98	1.166	25.139	0.885	17.704	<0.001	160	0.275
enjoyment	Enjoyment	3.15	0.088	3.48	0.091	6.748	0.01	251	0.026

M[1] (mean), SD (standard deviation). N[2] (sample size), partial η^2 (effect size).

4.2. Characteristic Identification Test—Leaf or Leaflet

Table 4 shows the test results in relation to the learning outcomes when differentiating between leaf and leaflet. To avoid falsification from a pre-test effect, the survey was carried out in a pre- and post-test inquiry on different tree species and was statistically evaluated [59].

Table 4. Descriptive statistic for leaf/leaflet recognition (% correct and false answers) (N = 197).

	Pre-Test							
	Reduced paper-based identification key				Digital identification key (ID-Logics app)			
	European Beech	Sycamore Maple	Common Hazel	Robinia	European Beech	Sycamore Maple	Common Hazel	Robinia
Leaf/leaflet	Leaf	Leaf	Leaf	Leaflet	Leaf	Leaf	Leaf	Leaflet
Correct	100	99.21	100.00	18.25	100.00	100.00	100.00	13.60
False	0.00	0.79	0.00	81.75	0.00	0.00	0.00	86.40
	Post-Test							
	Reduced paper-based identification key				Digital identification key (ID-Logics app)			
	Pedunculate Oak	Norway Maple	Hornbeam	Common Ash	Pedunculate Oak	Norway Maple	Hornbeam	Common Ash
Leaf/leaflet	Leaf	Leaf	Leaf	Leaflet	Leaf	Leaf	Leaf	Leaflet
Correct	97.62	99.21	97.33	30.16	98.40	96.80	97.60	60.00
False	2.38	0.79	2.67	69.84	1.60	0.80	2.40	40.00

This learning outcome was statistically significantly different with a medium effect size between the two tools used by the students only for the leaflet condition, $F(2,195) = 21.3$, $p < 0.000$, partial $\eta^2 = 0.098$). Figure 3 shows the proportion of correctly identified leaflets in the pre- and the post-test for both tools.

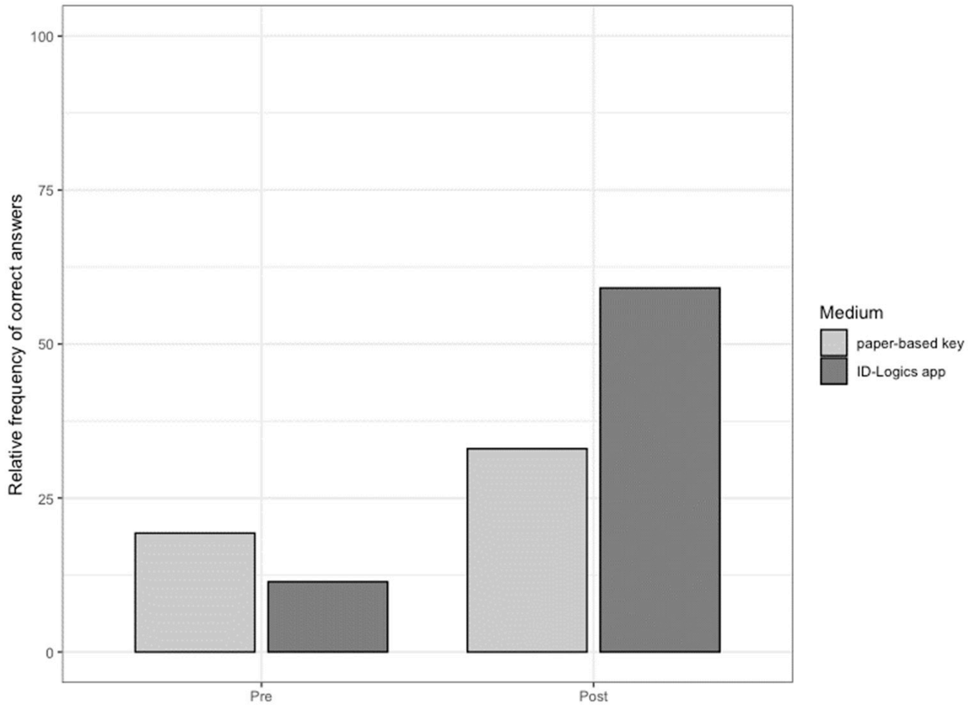

Figure 3. Leaflet recognition pre- and post-test (N = 197).

4.3. Species Learning

The type of identification tool used by the students had no significant effect on the students' ability to remember the identified species ($p = 0.88$). Students were able to remember 3.40 species on average when using the ID-Logics app and 2.88 species when using the paper-based identification tool ($F(1,235) = 2.943$, partial $\eta^2 = 0.020$).

In contrast, gender had a statistically significant influence ($p < 0.001$) on the students' ability to remember the identified species (Table 5). In general, female students performed better than male students, regardless of the tool used (mean female: 3.790; mean male: 2.486).

Table 5. ANOVA results for remembering the identified plant species.

	Reduced Paper-Based Identification Key				Digital Identification Key (ID-Logics App)				p_{female}	p_{male}	$d_1{}^2$	$d_2{}^3$
	Female		Male		Female		Male					
	M[1]	SD	M	SD	M	SD	M	SD				
Rem. Spec.[4]	3.76	1.79	2.00	1.79	3.82	1.79	2.97	1.79	0.889	0.028	−0.033	−0.541

M[1] (mean), SD (standard deviation). $d_1{}^2$ (Cohens d for comparison of tools in the female subgroup). $d_2{}^3$ (Cohens d for comparison of tools in the male subgroup). Rem. Spec.[4] number of correctly remembered species [0 to 5].

Overall, the interaction of medium and gender was not significant (p = 0.13). On average, females performed better than males and the results between the two tools used did not differ significantly (Mean females: paper-based tool = 3.76, digital tool = 3.82). However, male students performed significantly better when using the digital tool than with the paper-based tool ($F(1,235) = 4.90$, $p = 0.028$, partial $\eta^2 = 0.033$ (Mean: paper-based tool 2.00, digital tool 2.97)). Here, the tool used had a small effect size.

5. Discussion

The aim of this explorative study was to investigate the effects of two different identification tools (digital polytomous and reduced paper-based dichotomous) using the adapted usability concept under realistic field conditions. The usability concept was expanded in the effectiveness category to include the two indicators of determining characteristics (leaf or leaflet) and learning species names. These additions were made in order to better assess the applicability for biology teaching.

Our investigation revealed interesting results: In terms of effectiveness, data show that students who worked with the reduced identification key were able to correctly identify more species on average. In terms of learning, the study shows that students using ID-Logics were more likely to correctly identify the leaflet characteristic. The data reveal that the tool used had no significant influence on species learning. However, in a subgroup analysis we found that male participants remembered more species when they used ID-Logics, while the tool made no difference in the case of females.

In terms of efficiency, the results show that students using the reduced identification key were able to identify plants faster. As to enjoyment, students using ID-Logics reported higher ratings.

Overall, both tools in our study have the potential to support students with the difficult process of plant identification in the field. However, our findings suggest different opportunities and challenges for each of the two tools. We will discuss the educational implications of these findings in the Section 7.

5.1. Effectiveness of the Tool

The first hypotheses concerned the effectiveness of the tool. H1a: 'Due to the visual scaffolding the ID-Logics app should be more effective than the reduced identification key'. Indeed, our results indicate that there is a significant difference between the two tools regarding the effectiveness. Students who used the ID-Logics app succeeded in correctly identifying a plant in 56% of the attempts, while the group using the paper-based key had a 76% success rate. Therefore, we fail to reject the null hypothesis 1a. Moreover, hypothesis 1a has to be revised to: 'Students who have used the reduced paper-based identification key can correctly identify more plants than students who have used the polytomous digital identification tool'. One explanation for this result may be the smaller species spectrum of the reduced paper-based dichotomous identification tool (25 species). The ID-Logics app, on the other hand, is a more comprehensive identification tool with a total of 192 species. This may increase the possibility of errors and lead to a lower success rate when using the ID-Logics app, as more features had to be identified during the identification process. However, the final identification step at species level could also explain the observed difference, because with ID-Logics, students need to choose between several (up to six) very similar species. Hence, the risk of confusion is higher in this step compared to a dichotomous key. Also, the reduced identification key not only limits the total number of possible species, but also eliminates in advance similar species that do not occur locally but could be confused with those existent on site. This makes it easier for students to distinguish between species at the characteristic level, as there are fewer similar characteristics of closely related species to choose from. However, the comparison of similar species in the app can encourage a closer look at selected characteristics. This could also have an impact on the learning of characteristics, as in total, fewer differentiated characteristics are presented in the reduced determination key. As an indicator for this, the ability to distinguish between leaf and leaflet was measured.

H1b: 'Due to the graphical presentation and the learner-designed assistance in the ID-Logics app, we assume that students will learn to recognise the leaflet better with this tool'. The ability to recognise specific characteristics of plants is of great importance for the correct identification of species. In the case of shrubs and trees, the leaf in particular represents an important feature for identification. In the past, students had problems distinguishing between leaf and leaflet [42,48]. In this study, the leaflet was correctly identified by only 11% and 19%, respectively, of the students before the intervention (Figure 3). Students tend to assume that leaves are undivided [28,40]. The results of our study support the assumption of a misconception of leaves: in the pre-test, nearly 100% of the students were able to correctly identify the leaf but less than 20% could identify a leaflet (Table 4). Therefore, our results coincide with the study of Affeldt, Groß and Stahl [48] and indicate that students face problems when plants do not match their inexpert concept of an undivided leaf. After the intervention, we observed a significant difference between students who used the ID-Logics app and those who used the reduced paper-based key. A total of 59% of the students who used the ID-Logics app were able to identify the leaflet after the intervention, whereas only 28% of the students who used the reduced identification key could identify the leaflet correctly. Therefore, we fail to reject the null hypothesis 1b.

The question arises as to why the two tools had such a different effect. One possible explanation could be the built-in support systems of the digital tool: the ID-Logics app can help students overcome learning barriers by presenting explanatory videos and specific supporting information. Furthermore, the identification process itself possibly helped the students to distinguish the characteristic of the leaflet. Since the digital tool ID-Logics is based on multiple graphical representations of one characteristic, students can more easily compare the original plant with this representation in the tool [42]. These authors concluded that the feature of emphasising plant characteristics in the ID-Logics app enabled the students to learn these characteristics more efficiently.

Does it also help students to learn species names when they are familiarised with specific characteristics? Overall, our results show that the tool had no significant effect on the ability to remember the species identified during the intervention. However, students using the ID-Logics app tended ($p = 0.88$) to remember more species (3.40) than students with the reduced dichotomous paper-based identification tool (2.88). This tendency should be further investigated. In this context, hypothesis H1c was created: 'Female students can remember more species correctly when using the ID-Logics app, due to a higher affinity for plants'. The findings indicate that the tool only had a significant effect on species learning in the male student group (Table 5). This influence may be due to the generally higher affinity of male students for digital media [60]. Since interest is a relevant factor for learning, digital media in general, and the ID-Logics app in particular, offer an opportunity to encourage male students. Nevertheless, we fail to reject the null hypothesis H1c, since females could in total remember more species.

5.2. *Efficiency of the Tool*

To investigate the efficiency of the two tools, we formulated a second hypothesis (H2): 'Due to a limited species selection of the reduced identification key, we assume that the task of identifying five species can be solved more quickly.' We fail to reject the null hypothesis 2 (Table 3). Students using the ID-Logics app required on average six minutes longer for the identification process than those using the reduced paper-based key. One reason could also be the higher complexity of the ID-Logics app and thus, difficulties in using this digital tool. This could also lead to a more intensive preoccupation with the graphical representation and the identification process itself. The program ID-Logics has a non-linear structure and distinguishing characteristics are presented based on previous input. This may have required the students to focus on each and every step of the identification process, especially when starting the identification process from the beginning. This feature of the program could also have reduced the students' cognitive load (based on their pre-knowledge), since they were rather guided by the program, and this could even have resulted in a higher attention effect for the students. It is also known that increased attention has a positive effect on learning [61].

5.3. Satisfaction with the Tool

But does a general difference in the enjoyment level exist? To assess this, the last hypothesis (H3) was created: 'Due to the graphical presentation, the individual support functions and the general enthusiasm of the students for technology, we assume that the ID-Logics app achieves a higher level of enjoyment than the reduced identification key'. We fail to reject the null hypothesis 3. Results show a small but significant difference in the enjoyment level of the students after they finished the identification process. This could be explained by a general higher affinity for digital tools used in the learning processes or with the novelty effect. Since students were not familiar with any of the identification tools, this effect should theoretically be equal for both tools. But since the ID-Logics app was graphically more advanced and offered different support functions (such as explanatory videos), this may explain the higher attraction for the students. For a more detailed breakdown of the motivational as well as the enjoyment aspects of the intervention, see [52].

6. Limitations

Comparing applications in a realistic school environment, even more so in the context of a field trip, is difficult, which is why limitations can exist in the transferability of results. For example, not all environmental factors and variables that are held constant in the laboratory can be controlled in the field. Although both applications differ in the species range, they are methodologically based on similar principles; namely, the pictorial comparison of characteristics. Another approach towards plant identification is the textual representation of the characteristics, as used by many expert keys. Expert keys often use technical terms of such a specific nature that they can be a decisive obstacle in the identification process for students. They often need help, because they cannot easily overcome these hurdles [42,48,62].

Since this was an intervention that took place during school lessons and included a total of three independent measurement points spread over several weeks, it is obvious that not all students could be present at all measurement points, for example due to sick leave. Indeed, 27 of the 310 students in the sample group reported sick for the field-trip. In addition, 86 of the 283 students who attended the field-trip were reported sick at the pre- or post-test. We assume that this proportion of missing values was a completely random figure. Furthermore, from the 283 students who attended the field-trip, we only generated 218 datasets for our analysis of the correct identification of plants. This is because 65 students failed to submit their results at the end of the station. A relationship between the missing data and their expected answers to the questions cannot be assumed. Due to technical problems, in the end, the data from 160 students were finally available for evaluation for the efficacy analysis. Since this was a random problem, we do not expect that the missing values will have a significant influence on the validity of the results presented.

In general, this intervention study should help to investigate the use of identification tools in a realistic school setting. The study shows that further studies are required to evaluate the effects of identification tools on learning, as well as their possible use in the classroom. Due to this practical approach, limitations exist in terms of the instruments, indicators and design used, as described above.

7. Conclusions

This intervention study reveals how important it is to examine digital media in detail, with respect to their individual advantages and disadvantages for teaching. Our results indicate that, taking different aspects of usability into account, there is no simple truth or automatic preference for the one solution or the other. The results we obtained were unexpected, leading to the rejection of many of our hypotheses. But what can we conclude from these findings, particularly for educational practice and for further research?

7.1. Comparing Apples and Oranges?

First of all, it is relevant to note that our study design did not simply compare an analogue with a digital tool. Rather, with both tools, the first step is a digital one. In order to use Eikes Baumschule, the teacher first needs to specify all relevant tree species of the field-trip area, so that the program can generate a dichotomous key from this information. Therefore, teachers need to familiarise themselves with the local tree species as an initial step and thereby already perform part of the identification process themselves. Our results indicate that, based on this pre-selection, the students have certain correlative advantages in terms of effectiveness and efficiency compared to the polytomous multi-access key ID-Logics. Should not the faster and more effective tool be generally recommended for use?

The collected data for the self-assessment of intrinsic motivation (enjoyment) in accordance with the intrinsic motivation concept [50] show that here, the enjoyment of determining a plant does not necessarily correlate with the speed with which a task can be solved, since the perceived enjoyment was significantly higher when using the ID-Logics app. Other factors such as the aesthetics of the plant or the observation of plants have been identified as important influencing factors for interest/motivation development in other studies [63]. But to this purpose, time is required, because speeding through the tasks obviously has a negative effect. Also, the use of ID-logics can promote the learning of specific plant attributes relevant for identification, as it especially emphasises the aesthetics and the characteristics of plants. This has also been described in other studies as a positive factor in combating plant blindness [63].

Thus, we argue here that reduced, pre-selected dichotomous keys such as Eikes Baumschule are suitable especially for the first attempts in the identification process, as they enable quick successes and thereby reduce the feeling of uncertainty on the part of the users. This in turn should promote the sense of autonomy as well as self-determination [63,64]. In contrast, digital media such as the ID-Logics app can play out their advantages in a later, more advanced stage of the learning process. They offer digital support, explanatory videos and assistance at appropriate stages and thus help the learner individually to autonomously overcome difficulties in understanding. ID-Logics is particularly suitable for learning the features of plants such as the relationships between structure and function. Furthermore, according to our results, male students in particular could benefit from the use of ID-Logics, although they are often more indifferent towards plants [23]. This could be due to a generally higher affinity for digital tools, which generates higher attention and thus supports learning. Future research approaches should examine these interactions more closely.

7.2. Educational Implications

Considering the findings reported above, we conclude that a combined teaching strategy for plant identification is probably the best way to stimulate students' interest in nature and their awareness of plant blindness and biodiversity loss. The aim is to combine the advantages of both instruments: As a first step, the students should quickly experience success and gain confidence in the process of plant identification. For this purpose, a reduced conventional identification key presenting a manageable selection of species is a good choice. The students should be made aware at an early stage that this tool can only be used in certain areas and therefore has a limited range.

In a second phase, an advanced digital tool comparable with ID-Logics should be introduced, as it can be used universally and provides further information about the plants and their specific characteristics. This not only empowers the students to use an identification tool independently in their environment; with the additional information it provides, it also offers the possibility of expanding knowledge about the individual species and thus the understanding of biodiversity, which in turn could reduce plant blindness.

Another benefit of combining both identification tools is that it potentially facilitates the internal differentiation in the learning group. Students with learning difficulties could benefit from the limited offer of the reduced identification key, as they would not be overwhelmed by the selection of different features. High-achieving students can benefit from the openness of the ID-Logics app and its universal applicability. Furthermore, educators should not only focus on the quantity of species identified, but rather on the quality of the identification process. Students often have problems identifying too many plant species during a lesson. This leads to stress and confusion, so that the intensity of engagement with the individual plant, the intended learning effect and the students' motivation are diminished. Therefore, it is generally better to identify fewer species, but with a higher level of detail, and to build on these experiences productively [65].

7.3. Next Steps

The desired answer to the question of whether modern identification media are a new solution to help overcome plant blindness is still unknown. But our findings suggest that the question is perhaps oversimplified, and that we should focus not only on the media, but rather on what we wish to achieve with their use: it is not a general question about the device itself, but rather, which is the right tool for a specific learning goal in science education. Both types of tools present specific opportunities and challenges [66]. That is why further research is needed into how the use of digital media affects student motivation, interest and learning in different environments. Other tools not considered in this study, such as the automatic image recognition of plants, also represent a potential opportunity to motivate laypeople to identify plants with a low-threshold offer. Therefore, these tools should also be investigated in future research with regard to their effects on the usability for teaching.

This study reveals the great opportunities that digital media offer when it comes to plant identification. As the availability of digital platforms such as smartphones and/or tablet computers is no longer a limiting factor, digital tools provide a usable method of enabling students to identify plants. Nevertheless, more research is required to better exploit the potential of digital media and to constantly improve the digital approach. Only if educators know the limits and possibilities of these tools, will they be able to use them effectively and generate interest in plants, fight plant blindness and increase awareness of the global decline in biodiversity. For this purpose, teachers not only need further empirical data on the effectiveness of the applications, but also specific in-service training to make use of them.

Author Contributions: Conceptualization, A.F.; Methodology, A.F.; Formal analysis, A.F.; Investigation, A.F.; Writing—original draft, A.F.; Writing—review & editing, J.G. and J.Z.; Visualization, A.F.; Project administration, A.F. All authors have read and agreed to the published version of the manuscript.

Funding: The publication of this article was funded by the Open Access Publishing Fund of Leipzig University supported by the German Research Foundation within the program Open Access Publication Funding.

Institutional Review Board Statement: Not applicable.

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

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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