World Journal of Chemical Education, 2020, Vol. 8, No. 1, 21-28
Available online at http://pubs.sciepub.com/wjce/8/1/3
Published by Science and Education Publishing
DOI:10.12691/wjce-8-1-3

Identification of Ants - Development of the Learner-Oriented Digital Tool ID-Logics

Jorge Groß, Joachim Langstein, Jürgen Paul, Eva Ritter*

University of Bamberg, Department of Science Education, Markusplatz 3, 96047 Bamberg, Germany
*Corresponding author: evaritter.hainert@gmx.de

Received January 05, 2020; Revised February 14, 2020; Accepted March 05, 2020

Abstract Ants are fascinating creatures and they have an enormous impact on most terrestrial ecosystems. Despite their importance, relatively few people are able to securely identify the various ant species. In addition, simultaneously to the worldwide extinction of species (especially of insects), the number of species experts is decreasing, not only in Germany. The aim of our project is to improve the possibilities of determination of species and get students back in touch with nature. Based on experiential realism, the learner-orientated and interactive species identification tool "ID-Logics" for ants was developed. Using the design-based-research approach and the model of educational reconstruction, students' conceptions were collected in an interview study (n=7). According to the interview analyses, three essential learning barriers were identified. To overcome these learning barriers, data-based solutions were developed. Therefore, digital components were evaluated in three teaching experiments (n=6). On the one hand, the results showed that students were able to describe basic characteristics of ants. On the other hand, learning obstacles occurred with certain characteristics where students needed assistance. For this, interventions such as abstract graphics or short videos can support them in the process of identification. Moreover, a fault tolerant programmatic logic was implemented to combine these components in the identification tool "ID-Logics". Based on our results, guidelines to develop further interactive identification tools are formulated.

Keywords: *species identification, app, students' conceptions, ants, design-based-research*

Cite This Article: Jorge Groß, Joachim Langstein, Jürgen Paul, and Eva Ritter, "Identification of Ants - Development of the Learner-Oriented Digital Tool ID-Logics." *World Journal of Chemical Education*, vol. 8, no. 1 (2020): 21-28. doi: 10.12691/wjce-8-1-3.

1. Introduction

Ants are extraordinary animals concurrently including many similarities with humans: waging wars, administering medicine, farming and grazing, using encrypted communication and effective working chains, secret poisoning and great physical strength. Making up nearly 15% of the entire terrestrial animal biomass, ants are impressive not only in quantitative terms, they also fascinate by their highly organized and complex social system [1]. In addition, they are of enormous importance to many ecosystems as they spread seeds, increase biodiversity, feed many other creatures and fight pests. They are the premier soil turners and channelers of energy. Ants have been omnipresent on this planet for millions of years. Around 13,000 ant species are known worldwide, distributed over 334 genera. As a result of the climate, only about 160 ant species were found in central Europe, which are divided into 4 subfamilies and about 33 genera [1]. Although many people know ants, they do not perceive them and are not aware of their high impact and their great diversity.

Despite this remarkable relevance, there are almost no usable identification keys for ants in science education (even at level of genus). This leads to a fundamental problem because species knowledge is crucial for conservation issues and human-animal interactions. The loss of biodiversity and abundance is expected to provoke cascading effects on food webs and whole ecosystems [2]. Therefore, in the National Strategy on Biological Diversity (NBS) of 2007 the German government emphasizes the importance of taxonomy education and species knowledge for the preservation of diversity [3]. However, the loss of biodiversity on our planet continues rapidly [4]. According to the new IPBES-Report, more than one million species of plants and animals are at risk of extinction [5]. Natural ecosystems have declined by 47% on average, relative to their earliest estimated states. Especially the worldwide entomofauna declines [6,7].

To overcome this problem and to restore a bond with nature, species identification is a basic requirement in species and nature conservation. But people who have special knowledge about plant and animal species ("species experts") undergo a profound change: a standardized survey of 70 experts who are themselves in the field of species detection and management showed a significant decline in species awareness in their personal environment by 21% in the last 20 years [8]. The great majority of interviewees saw the problem of the decline of species experts. This clearly indicates the existence of a nationwide challenge, since more than 90% of respondents also proclaimed a very high or high importance of nature conservation in the future.

Therefore, a first step is to experience nature and to identify various species. Several studies on species knowledge and on methods how to acquire and to teach it have been conducted [9,10,11,12]. These studies have shown that young students have a poor or very limited species knowledge. Acquiring or improving this knowledge are difficult tasks. One reason for this seems to be that students nowadays rarely experience nature directly. Instead, the new media usually play a dominant role in students' everyday life. According to the latest Bitkom study [13], 67% of 10 to 11-year-olds and already 92% of 14 to 15-year-old students own a smartphone. Accordingly, it makes sense to address young people through this medium. By this, children and young adults also can be included. Those age groups are very affine to digital media, but only few of them are represented in nature conservation.

In this research project we therefore combined experiencing nature and digital media by developing an interactive identification tool called ID-Logics (available on the App Store for iOS and Google Play for Android). In our research, we focused on the ability to identify ants mainly based on their morphological characteristics, occurrence, and specific behaviour. In contrast to other identification tools (overview see [14]), we developed and evaluated a tool based on a close collaboration of science education researchers, biologists, and students aged 13 to 15 years in Germany. Based on the evaluation results, guidelines to design an educationally structured interactive identification tool are formulated. The main research question is:

- How does a species identification tool have to be designed to determine ants in a learner-oriented way?

Guided by the model of educational reconstruction [15,16], the evidence-based development of this interactive identification tool was structured by the following three steps:

1. Process description of species identification from an educational perspective.
2. Collection and analysis of students' conceptions of ant characteristics.
3. Identification of challenges in the process of ant identification and developing solutions for the App "ID-Logics".

2. Theoretical Background

This research is based on a moderate constructivist epistemology [17]. We see students as individual learners who construct their knowledge in an active and self-regulated procedure on the basis of existing conceptions. In accordance with this, the learning process cannot be controlled completely by external factors but can be initiated by learning environments. Students thereby use their experiences and their ensuing thoughts about these experiences. Those conceptions derived from everyday experiences can be beneficial or obstructive for learning. However, learning can be initiated by learning environments and their parts like an interactive identification tool. Also, learning takes places in social environments and is connected with contextual experiences that influence learning. To clarify the process of learning, the cognitive metaphor theory (CMT) [18] is used to interpret students' concepts in order to gain a deeper understanding of their ways of thinking. The theory describes the interrelationship between experiences and understanding. Based on this theory of understanding a relationship between experiences, thinking and speech can be built.

The model of educational reconstruction structures this research [16]. It combines and relates three complementary components: *scientific content*, *students' capabilities* and *learning environments* (see Figure 1).

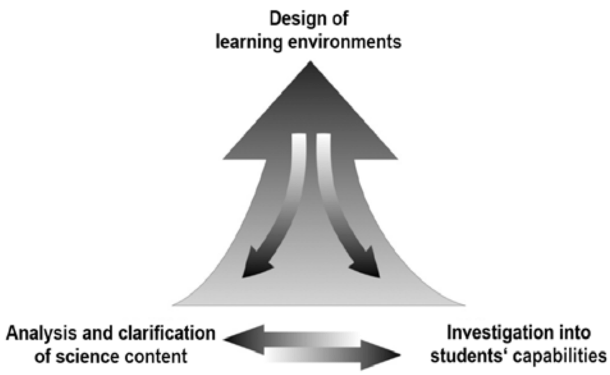

Figure 1. The model of educational reconstruction (modified Gropengießer & Kattmann, 2009).

The scientific content is clarified and analyzed critically. Students' capabilities are investigated in interviews and teaching experiments [19]. Based on these results, learning environments for ant identification are developed and evaluated. These three components of the model (scientific content, students' capabilities and learning environment) are related in a recursive process. This means that the components are not viewed individually. Instead, they are related to each other in a repeating process of clarification, development and evaluation. This enabled us to get implications on how to design and evaluate our interactive identification tool as a central element of a learning environment fostering ant identification.

Also, a process model of species identification has been developed and applied in the development and evaluation of the identification tool. It is based on the complexity levels of conceptions by Gropengießer [20] and includes three components:

1) Sign: Texts or graphics of characteristics.
2) Conception: Students' conceptions of characteristics.
3) Object: Original objects with varying characteristics.

The structure of the process of species identification is based on the semiotic triangle [21]. In the identification process the learner relates an object (e.g. head of the ant) to a sign (e.g. a graphic) based on his conceptions (see Figure 2). The learner therefore compares object and sign and decides whether they match or not according to their similarities. Based on cognitive linguistic findings we are able to characterize individual ways of thinking and determine how interventions foster (or hinder) students' thinking and learning in the process of species identification.

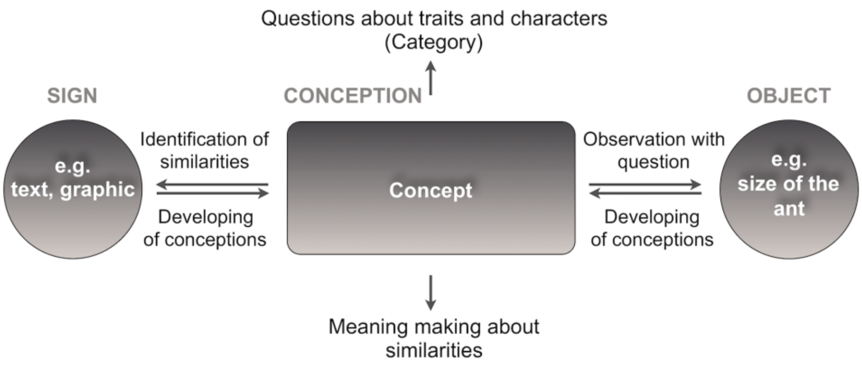

Figure 2. The process model of species identification with its three components sign, conception and object

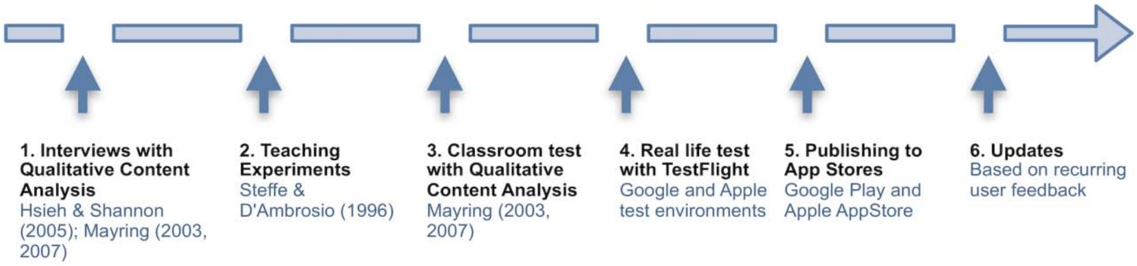

Figure 3. The methodical framework of the investigation

3. Materials and Methods

Based on the design-based-research approach [22] an evidence-based program for ant identification should be developed. By means of recurring research data on the identification process, indications for the development are to be derived.

Following the model of educational reconstruction, we clarified the relevant scientific characteristics to identify the ants. Here we follow the approach of Educational Design Research [23]. In close collaboration with a botanist and a zoologist we investigated which characteristics are important from a scientific point of view to identify ant species. The collection of students' conceptions was structured in two studies.

In our first study, we conducted interviews to investigate which characteristics students can basically describe. This first study was necessary since we could not rely on existing data or results concerning students' conceptions of ant characteristics. We used a structured guideline to align the interviews for reproducibility. The interrelationship between questions and answers was validated by three different researchers based on qualitative content analysis [24]. In addition, an internal triangulation process with similar questions on the same issue was integrated into the guideline. We interviewed seven students aged 13 to 15 in 45-60-minute sessions. All interviews were recorded, transcribed and analyzed using qualitative content analysis [24]. This method includes the following five steps: (1) transcription of voice recordings, (2) editing transcripts (transferring students' statements into a grammatically correct form), (3) organizing students' statements (summarizing the same or similar statements within one interview), (4) explication (interpreting statements by identifying conceptions and underlying experiences), and (5) structuring (formulating associated concepts). For reliability, coding and interpretation of students' statements (steps 4 and 5) were analyzed by two researchers working independently. The findings of both were then reconciled if necessary. In the interviews, we asked students to describe ants. For example, students were given selected pictures of ants and they were supposed to describe as many characteristics as possible. Or the students were presented three different types of ants and had to describe the ants' similarities and differences in as much detail as possible. The description of the ants indicated which characteristics the students noticed, and which were neglected. Also, the qualitative approach enabled us to gain a deep insight into the students' individual conceptions about ants.

Our second study was based on our results of the first study. According to these results, several components of an interactive identification tool were developed. The evaluation of the components was done in teaching experiments [19,25]. We asked 3 pairs of students aged 13 to 14 in 60-75 minutes teaching experiments. The data were recorded and analyzed by using qualitative content analysis [24]. Teaching experiments offer possibilities to combine teaching situations (interventional aspect) with interview situations (investigational aspect). Also, by asking pairs instead of single students we created situations more similar to lessons at school to get a deeper understanding of their conceptions.

In the teaching experiments, single components of the identification tool were evaluated separately step by step. This was necessary in order to analyze the relation between each sign and the object according to the process model of species identification (see Figure 2). By evaluating the components separately, we were able to analyze possible effects of the individual parts before implementing them into the identification tool for ants. First, questions and abstract graphics were evaluated. For example, students were presented different ant species and were supposed to assign them to the according abstract graphics. Secondly, short video sequences were evaluated. For example, a video of the symbiosis with caterpillars or aphids was presented to students to assess whether it helps them to properly recognize the symbiosis.

According to the process model of species identification (Figure 2), the data collected from the interviews and teaching experiments enabled us to systematically design and evaluate a learner-oriented identification tool for ants. In the following chapter, exemplary results of the two studies are presented.

Our digital tool helps to identify ants not to the species level but only to the level of genus. This is for two reasons: (1) Ants comprise a great variety of species, some of which are extremely difficult to distinguish also for experts. We do not want students to get frustrated when speculating on sophisticated characteristics. Instead, we want students to get in touch with nature and to precisely look at visible and accessible characteristics. (2) In some cases, special equipment such as microscopes would be needed to securely identify certain ant species. Since our tool is thought to be used also in nature and also by students and other non-scientists, special equipment is not always available. The aim of this identification key at the genus level therefore was to find and develop soft determination criteria that an interested person without prior knowledge of morphology and terminology, and with a few simple tools (tweezers, magnifying glass), can assess in an ant. However, we still use the term "species" in this article when addressing the identification process as we refer to other databases of the app ID-Logics as well, all of which determine to species level.

4. Results and Discussion

The results presented here are based on the analysis of students' conceptions in our first and second study. The data indicate that identifying species is indeed a tricky task. Based on our theoretical framework, we diagnosed several educational challenges in the process of species identification for ants. The data largely confirms the data from previous studies [2,26]. In the following, three central learning barriers for species identification and their corresponding solutions are presented.

Learning barrier 1: The dichotomous way is often misleading

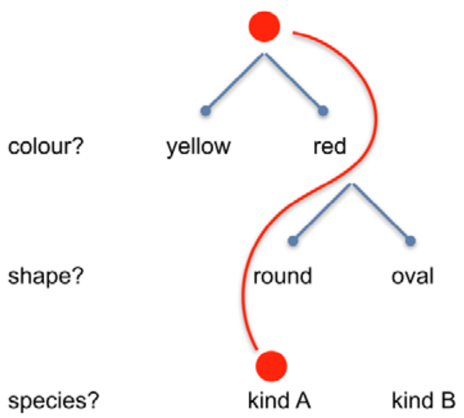

Figure 4. The dichotomous way

Existing printed keys for species identification have so far been a question-and-answer system: asking questions attempts to divide a species group further and further until only one species remains [27]. We call this the dichotomous way see (Figure 4). Disadvantage of this procedure is that in the end there is only one path leading to the right kind. This way does not tolerate any fault. Already one deviation leads to the wrong result. And the teacher can hardly understand where the wrong path was taken. This type of determination has often proved frustrating and demotivating to students.

Overcoming the learning barrier 1: The intelligent program logic

Based on our data, we were able to assume two results: On the one hand, students recognize a lot of details when they are directly pointed to specific characteristics. On the other hand, these could not always be assigned correctly. So, the challenge arose: What characteristics are suitable for the determination of ants? Therefore, we have developed an intelligent program logic. In contrast to usual determination literature, the app asks questions whose answers are easy to reply and reduce the group of possible species not relevantly. Based on the remaining amount of possible species, the logic of the app calculates further, simple questions. Moreover, the user is allowed to skip single questions by clicking "I cannot recognize it". An intelligent triangulation of the data then identifies the right species based on the given answers. Advantage of this polytomous method is that the mechanisms works fault tolerant. Wrong answers do not automatically lead to incorrect determination. Due to the triangulation, the app can carry characteristics that were not clearly supported by the previous student survey. In contrast to other interactive identification tools, it is a complex logic that combines several factors: the order of questions and the reaction to given answers. Based on the logic, the tool only poses questions that are most likely to reduce the number of species in question effectively. Also, the logic assesses which question to ask next after each identification step. For example, a student chooses an answer. Based on this answer the logic sorts out those species that do not have the chosen answer. Moreover, the logic assesses which answer to ask next to reduce the remaining number of species-based characteristics of the remaining species. Therefore, the order of questions varies according to the given answers in every species identification process.

In addition, the way is logged, so that at any time a transparency in the reduction process can be reconstructed.

Learning barrier 2: Students need a structured identification

The analysis of the interview data showed that students generally identify several ant characteristics correctly, such as colour of the body or size of the ant. However, some differences in the descriptions occurred.

Students are able to describe most of the scientific relevant characteristics of the body. In contrast to scientists, however, students focus only on highly visible characteristics; dealing with enlargers and perceiving them in the microcosm are difficult for them. They focused on the description of the body and mostly portrayed their shape, colour, structure or size. In contrast to scientists, they generally did not use scientific terms to describe characteristics and their values. For example, in case of the one or two petioles between the thorax (mesosoma) and the abdomen (gaster) they used descriptions like “hill” or “huckle”. Also, students sum up various characteristics that refer to different characteristic values. Therefore, there was no consistent structure in their description. In all of the interviews, students focused on the size, colour and structure of the body of the ants. These characteristics were partly described in great detail. However, characteristics such as the antennae elements or the mandibles that are scientifically important to identify ants went unnoticed.

Overcoming the learning barrier 2: Structuring the identification process

In order to solve »learning barrier 2«, two solutions were developed: *questions* and *abstract graphics*. These components were evaluated in teaching experiments. In the teaching experiments, students were handed several ants of different species. Then, they were given a question to a certain character, e.g. *What is the shape of the ant’s nest?* or *What is the structure of the ant’s midbody?* The questions were formulated avoiding complicated scientific terminology so that students could understand them without scientific knowledge. Also, in one question only one characteristic was addressed. To answer the question of the present criterion, abstract graphics of the characteristic values were presented. We used abstract graphics because other studies have shown that students seldomly read textual information [2,28]. Therefore, we developed educationally structured graphics following the results of the clarification of scientific content and students’ conceptions. Also, complex scientific terminology was avoided, and characteristics have been chosen which are more accessible to students. We developed four types of graphics to display characteristics and their values (see Figure 5):

1) **Shape:** Visualizing possible characteristic values completely, e.g. shape of the petiole.
2) **Detail:** Localizing the characteristic on the individual and showing parts of the characteristic values, e.g. surface of the head.
3) **Colour:** Localizing the characteristic on the individual and showing a selection of colours, e.g. colour of the gaster.
4) **Number:** Localizing the characteristic on the individual and showing a selection of numbers, e.g. covered distance within 5 sec.

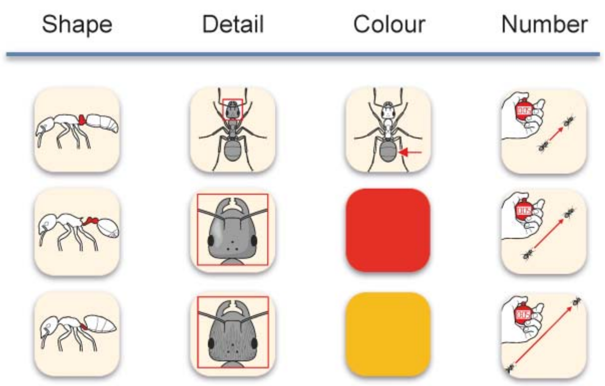

Figure 5. Four categories of educationally structured graphics to determine ants

In the teaching experiments, the students had to assign the ants to the according graphics. For example, they had to decide which abstract graphic of the petioles is similar to the shape of their original petiole. Or they had to choose which colour of the head is most similar to their original colour.

In general, students understood the questions and were able to locate the according characteristic and their values correctly. The questions helped them to focus on one characteristic at a time. Also, the abstract graphics supported them to identify the correct characteristic of the ants. The transcript shows an exemplary quote from a teaching experiment. In this situation, Sophie (13 yrs.) describes abstract graphics of different nest types of ants and where to find these types on the original terrain:

“*In the graphic you can see certain types of nests. The first graphic looks like a stone and below is the nest [pointing to a floor nest]. These are just several hills [points at the graphic of the hill nest]. White lines are the passages dug by the ants. There are so few connections in between, such tunnel systems, connecting the hills*”.

The example indicates that educationally structured graphics can support students. They were mostly able to compare the signs (graphics and text) with their objects (ants) successfully. The graphics assisted students to explore and to focus on one characteristic and their values. The structure of question and answer guided the students effectively in most cases. However, some characteristics still proved difficult for the students. These learning obstacles are presented in the following.

Learning barrier 3: Obstacles with unknown characteristics

The results of evaluation of the questions and abstract graphics showed that students faced learning obstacles associated with certain characteristics. In the following, the case about symbioses between ants and other insects is exemplarily presented in detail.

Figure 6. Ants live in symbiosis with aphids (*Aphidoidea*, picture: J. Langstein)

In the case of symbioses, the differentiation of insects was an educational obstacle for the students. When assigning insects like an aphid or a mealybug, they were not aware of the differences. Essential learning barrier were that learners do not know what an aphid or a lycaenid larva looks like or they have never heard about. For this reason, the drawings were misinterpreted except for the caterpillar. In this case, the students’ conceptions of an insect differed from the scientific perspective. Zoologist distinguish between these insects easily and therefore easily identify the symbiosis (see Figure 6).

Examining the data based on the theory of experiential realism [18], students used their basic-level concept of insects. Those concepts are related to our everyday experiences and disregard complex issues of scientific conceptions. According to these everyday experiences, no benefit for insects is seen and consequently a symbiosis with partnerships cannot be recognized. Therefore, the students did not apply the concept of symbiosis at all. Instead, a typical student conception inspired by the photo (see Figure 6) was, that an ant eats the other creatures (aphids). Furthermore, the questions and abstract graphics did not support all the students sufficiently to assign the correct graphics to their symbiotic insects. But since it is necessary to be aware of symbiotic insects when identifying ants, students need further assistance.

The data showed that students' conceptions of insects hindered them to assign the correct abstract graphic. The symbiosis is an important biological feature for scientists. When students tried to answer the question concerning the symbiosis, they drew their attention to known insects and described aphids as grasshopper or other known insects. The following interview shows the conceptions of the students to the pictures before using the videos:

Interviewer: "O.K. Let's move on to the next picture: Is the ant in association with other insects? How would you interpret the pictures now if you read the question and see the pictures?"

Student A: "Which animal belongs to the ants?"

Interviewer: "Mm. And what could that mean?" […]

Student B: "The second picture looks like a caterpillar. And the third is more like a bug and the first looks like a grasshopper or something."

Student A: "Some ants have built their nests to live together with others, like larvae -not to be alone but share with animals. Like a shared flat for humans, only for animals."

These example of the evaluation of the questions and graphics clarify that students can face different obstacles in the process of species identification. Further learning obstacles in case of the ants occurred for example with Polymorphism, nesting or agility. Students could not overcome the identified obstacles by themselves. Therefore, solutions had to be developed to assist the students effectively. These solutions were evaluated in teaching experiments as presented in the following.

Overcoming the learning barrier 3: Support the learner with short videos

The results of the first teaching experiments showed that students' conceptions of certain characteristics differ from those of scientists'. Students can be misled by ambiguous scientific terms or look for the characteristic in the wrong spot. These learning obstacles hinder students to assign the correct graphic and therefore identify the species correctly.

Consequently, interventions were developed to support the learners in the process of species identification. In our study we developed short 16-30 second video sequences based on the identified learning obstacles like polymorphism, aggressiveness, nesting, agility or symbiosis. The design of the videos was guided by the principles for the design of multimedia messages by Mayer [[29], p. 184]: Animated pictures are shown simultaneously with narrated information. The videos contain information about the characteristic's appearance, function or where it is located. In total, 5 videos for ants were produced. In the following, exemplary results of the evaluation are presented.

In the case of the »symbiosis« example, the developed video explains how to identify the correct insects as follows:

Claim: Food for protection!

Often you will find ants along with aphids. If an aphid receives the signal of an ant, it excretes a sugary drop for the ant, which it picks up with its mouthparts. In return for food, the ants protect aphids from predators. Similar symbioses, i.e. partnerships with mutual benefit, also exist with mealybugs or lycaenid larva.

As shown in the example before, ambiguous scientific nomenclature is avoided in the video's information. Instead, less ambiguous terms were used, and the mutual benefit of the species is highlighted. At the same time, this also makes it possible to recognize the species better. In the teaching experiments, students watched the video when they had problems to discover the symbiosis correctly. In the following, exemplary conceptions of Alfred (13 yrs.) and Kurt (13 yrs.) after watching the video are presented:

Interviewer: "Do you have a better idea now?"

Student A: "Yes."

Student B: "Yes. Without the video, I would not have known anything except the caterpillar. But you cannot see a caterpillar in the video either."

Student A: "And I still do not exactly know that root louse."

Student B: "I've never seen ants with aphids together. I did not know that they live together like that."

Student A: Yes, we understand that the aphids give off such a drop on the back of the head and the ants protect them."

The example shows that the developed videos can assist students in the process of species identification. They clarify the relationship between ants and other insects and its function so that students can use the characteristics correctly to identify the species.

5. Conclusions and Implications

The results of the studies indicate that identifying species can be a difficult task. During the process of ant identification, students face obstacles that they cannot overcome on their own. They need structured assistance to identify or locate characteristics of ants correctly. In this paper, three central learning barriers and corresponding solutions were presented. The results of the evaluation clarify that the solutions can support students in the process of identifying ant species. Based on the results of the two studies, the following guidelines for developing an interactive identification tool are formulated:

1) Analyze the scientific content and students' conceptions of the corresponding group of species.
2) Structure the identification process in question (characteristics) and answers (characteristic values).
3) Use educationally structured abstract graphics.

4) Identify possible learning obstacles.
5) Support the learner with short additional information.
6) Use an intelligent programmatic logic.

Following these guidelines, an interactive identification tool for ants was designed (see Figure 7).

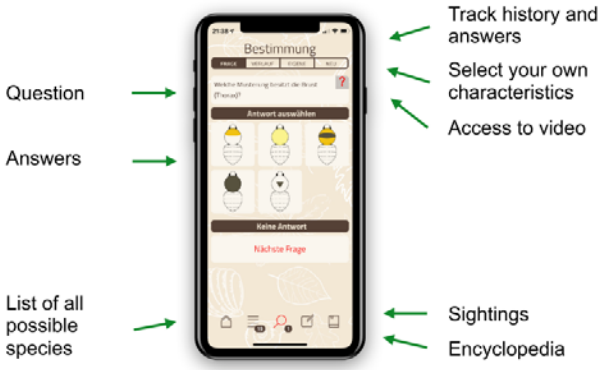

Figure 7. The species identification App "ID-Logics"

The developed questions, abstract graphics and videos were implemented into the interactive identification App "ID-Logics". These are improvements that directly support the students in the process of species identification. However, in the course of the development it became obvious that an intelligent logic was needed to combine these effectively in an interactive identification tool (see guideline 6). Additionally, students can compare their real individual ant with detailed descriptions and pictures of the remaining ant genera at the end of the identification process in the App "ID-Logics. Thus, the implemented logic offers a quick and effective way to identify species from a student's perspective. A first evaluation of the identification tool for clams supports these results [2,26]. Despite this high effort, the integrated fault tolerance, and the videos, the evaluation showed that several students still got wrong identification results. On the one hand, it could not be ensured that students really took advantage of the offered videos. On the other hand, species determination remains a major challenge, which requires appropriate support from teachers. However, the integrated fault tolerance enabled students to end up with the right ant genus, although if they answered single questions incorrectly.

Meanwhile, the developed App is available in the stores also for trees, marine clams, bumblebees and geophytes. It offers possibilities to be used in formal educational contexts (schools) and in informal educational learning environments (e.g. national parks). Also, the intelligent logic can be transferred to other groups of species. Since the application has a modular structure, the determination of other species can be made possible as simple databases. By using a content management system (CMS), the app should be extended continuously by further groups of species.

All in all, the tool ID-Logics helps students to identify and therefore name species they did not know before. And the awareness of species is the prerequisite for their protection and for preservation of biodiversity in general. In the next step, we are testing the chances of working with the app in a citizen science project with an external NGO for nature protection. We use the app to allow laymen to identify animals and collect their sightings for further use on an interactive website.

Acknowledgments

The project is funded by the Federal Environment Foundation (Deutsche Bundesstiftung Umwelt, DBU), the Joachim Herz Stiftung, Hamburg and the Bingo-Umweltstiftung, Niedersachsen. We thank Prof. Dr. Bert Hölldobler for scientific assistance and Sebastian von Sauter with his team for the good technical cooperation.

Statement of Competing Interests

The authors have no competing interests.

References

[1] Hölldobler, B. and Wilson, E. O. *The Ants*. Springer Verlag, Berlin, Heidelberg, 1990, pp. 732.

[2] Groß, J., Affeldt, S. and Stahl, D. Find my Name! Evidence-based Development of an Interactive Species Identification Tool. In: I. Eilks, S. Markic and B. Ralle (Eds.). *Science education research and education for sustainable development*. Shaker, Aachen, 2019, 97-108.

[3] BMU. *Nationale Strategie zur biologischen Vielfalt* [National Strategy on Biological Diversity] (NBS). Hrsg. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), Berlin, 2007.

[4] Secretariat of the Convention on Biological Diversity, *Global Biodiversity Outlook 3*. Montréal, 2010, 94 p.

[5] IPBES. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. S. Díaz, J. Settele, E. S. Brondizio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany, 2019.

[6] Sanchez-Bayo, F., Wyckhuys, K.A.G. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation 232*, 2019, 8-27.

[7] Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., et al. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE* 12(10): e0185809, 2017.

[8] Frobel, K. and Schlumprecht, H. *Erosion der Artenkenner* [Erosion of species connoisseurs]. Abschlussbericht im Auftrag des BUND Naturschutz in Bayern e.V. Nürnberg 2014, 92 S.

[9] Lindemann-Matthies, P. The Influence of an Educational Program on Children's Perception of Biodiversity. *The Journal of Environmental Education, 33*(2), 2002, 22-31.

[10] Bromme, R., Stahl, E., Bartholomé, T. and Pieschl, S. The case of plant identification in biology: When is a rose a rose. In P. P. A. Boshuizen, R. Bromme, and H. Gruber (Eds.), *Professional learning: Gaps and transitions on the way from novice to expert* (pp. 53-71). Kluwer Academic Press, Dodrecht, 2004

[11] Bebbington, A. The Ability of A-level Students to Name Plants. *Journal of Biological Education, 39*(2), , 62-67.

[12] Randler, C. and Bogner, F. X. Cognitive achievements in identification skills. *Journal of Biological Education, 40* (4), 2006, 161-165.

[13] BITKOM (Eds.). *Digitale Schule - vernetztes Lernen: Ergebnisse repräsentativer Schüler- und Lehrerbefragungen zum Einsatz digitaler Medien im Schulunterricht*. [Digital school - networked learning], Eigenverlag, Berlin, 2014.

[14] Stevenson, R. D., Haber, W. A. and Morris, R. A. Electronic Field Guides and User Communities in the Eco-informatics Revolution. *Conservation Ecology* 7(1), 2003.

[15] Duit, R., Gropengießer, H. and Kattmann, U. Towards science education research that is relevant for improving practice: The

model of educational reconstruction. In: H. E. Fischer (Ed.). *Developing standards in research on science education* (pp. 1-9). Taylor and Francis, London, 2005.

[16] Gropengießer, H. and Kattmann, U. Didaktische Rekonstruktion - Schritte auf dem Weg zu gutem Unterricht. In B. Moschner, R. Hinz and V. Wendt (Eds.), *Unterrichten professionalisieren*. [Professionalize education.] Schulentwicklung in der Praxis (pp. 159-164). Cornelsen, Berlin, 2009.

[17] Duit, R. and Treagust, D.F. Learning in Science: From Behaviourism Towards Social Constructivism and Beyond. In: Fraser, B.J. and Tobin, K. G. (Eds.). *International Handbook of Science Education* (pp. 3-25). Kluwer Academic Publishers, London, 1998.

[18] Lakoff, G. and Johnson, M. *Philosophy in the Flesh*. New York: Basic Books, 1999.

[19] Steffe, L. P. and D'Ambrosio, B. S. Using teaching experiments to understand students' mathematics. In D. Treagust, R. Duit and B. Fraser (Eds.), *Improving teaching and learning in science and mathematics*. Teacher College Press, New York, 1996, 65-76.

[20] Gropengießer, H. *Lebenswelten, Denkwelten, Sprechwelten*. Wie man Schülervorstellungen verstehen kann. [Worlds of living, speaking, and thinking: How to understand students' conceptions.] Didaktisches Zentrum (Beiträge zur Didaktischen Rekonstruktion, Bd. 4), Oldenburg, 2006.

[21] De Saussure, F. *Grundfragen der allgemeinen Sprachwissenschaft*. [Principles of general linguistics.] Walter de Gruyter, Berlin, 2001.

[22] Design-Based Research Collective, Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32 (1), 2003, 5-8.

[23] Plomp, T. and Nieveen, N. (Eds.). *Educational Design Research*. Part A: An introduction. SLO, Netherlands institute for curriculum development, Enschede, 2013.

[24] Mayring, P. *Qualitative Inhaltsanalyse*. [Qualitative content analysis.] Beltz Verlag, Weinheim, 2010.

[25] Katu, N., Lunetta, V. and Van den Berg, E. *Teaching experiment methodology*. Paper presented at the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Ithaca, New York, 1993.

[26] Stahl, D. *Didaktische Rekonstruktion zur Artansprache heimischer Bivalvia* [Educational reconstruction of species identification concerning native bivalves] (Vol. 42). Didaktisches Zentrum, Oldenburg, 2013.

[27] Hashimoto, Y. Identification guide to the ant genera of Borneo. In Hashimoto, Yoshiaki, and Homathevi Rahman (eds.): Inventory and Collection - Total protocol for understanding of biodiversity, *UMS press*: 2003, 89-162.

[28] Groß, J. *Biologie verstehen: Wirkungen außerschulischer Lernangebote*. [Understanding Biology: Effects of informal learning environments.] (Vol. 16). Didaktisches Zentrum, Oldenburg, 2007.

[29] Mayer, R. E. *Multimedia Learning*. New York: Cambridge University Press, 2001.