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The effect of microlevel and macrolevel signaling on learning with 360° videos

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Abstract

The application of 360° videos raised the attention of educators and researchers, as it appears to be an approachable option to mediate complete environments in educational settings. However, challenges emerge from the perspective of educational psychology. Learning irrelevant cognitive strains might be imposed because it is necessary to navigate through spherical material. However, these potential downsides could be compensated for using signaling techniques. In a two (macrolevel vs. no macrolevel signaling) × two (microlevel vs. no microlevel signaling) factorial between-subjects design plus control group, 215 fifth-and sixth-grade students will watch a 360° video about visual and behavioral characteristics of animals. Learning outcomes, cognitive load, disorientation, and presence will be investigated. It is expected that macrolevel signaling will enhance learning and presence and reduce cognitive load and disorientation. Microlevel signaling will have comparable advantages, but these effects will be more pronounced when macrolevel signaling is implemented.

KEYWORDS
360° video, omnidirectional video, signaling, spherical video

1 | INTRODUCTION

360° cameras are capable of recording complete surroundings by capturing more than one picture simultaneously and composing them together. The viewer can then select an individual image detail within the complete initial scene. Thus, learners can participate in a balloon ride into the stratosphere (BBC Earth, 2019), be immersed in a jump from a ski jumping hill (Sportschau, 2016), or experience the struggles of a young male lion from a few inches away (National Geographic, 2017). All these examples would not be possible to experience in person by the average student. In addition, in comparison to traditional videos, they benefit from an omnidirectional perspective. For instance, complete surroundings provide more indicators of movement and transport and a clearer perception of speed and height during ski jumps. Being immersed in the situation allows for a more detailed observation of objects and their interactions (e.g., the individual lions and their social interactions).

Apart from entertainment purposes, such video material has been used within a wide variety of topics, such as sports, news coverage, and, of course, education (for detailed examples, please see Araiza-Alba et al., 2020; Barreda-Ángeles et al., 2021; Ivars-Nicolás et al., 2020; Shafi et al., 2020). Particularly for this purpose, such videos provide several benefits (Violante et al., 2019), including the potential to take on others' perspectives, experience otherwise inaccessible situations, or perceive a sense of freedom by choosing an individual vantage point. This can also be used to let learners "experience" the learning content in a playful way. For instance, to learn how camouflage and mimicking work, learners can be virtually placed within a terrarium and search for hidden insects (Figure 1).

The learning potential has been acknowledged by the creators of tools such as *Expeditions* (Google VR, 2021) trying to tailor 360° material to educational applications. In addition, research addressing

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relevant issues, such as which interface to use (Rupp et al., 2019) or comparisons to other types of media (Araiza-Alba et al., 2021), has begun to emerge. A recent literature review outlined that 360° videos are particularly suitable for learning contexts involving practical scenarios (Ranieri et al., 2022). The authors outlined that, when carefully implemented, the use of 360° videos in education has positive effects on learning, especially with regard to motivation, attentiveness, information retention, and transfer of knowledge. However, they acknowledged that research on this type of stimulus is still in its infancy, and only a minority of the investigated studies include a sample sufficient to address relevant research questions beyond explorative investigations.

However, as promising as the recording and archiving of complete surroundings may sound to an educator, it transfers the task of selecting and observing the optimal image detail from the creator of the instructional material to the learner. While simply watching the video material in real time, the chance of missing essential information or being distracted by learning-impairing elements might increase (Kavanagh et al., 2016). Thus, it might be especially advised to use multimedia design principles such as signaling or cueing (Mautone & Mayer, 2001; Schneider, Beege, et al., 2018; van Gog, 2014) to lead and capture learner's attention and to support the learning process. However, implementations of such design approaches within 360° videos are currently based on theoretical considerations (Violante et al., 2019), but not on empirical evidence. This is in contrast to other forms of new video learning material, such as interactive videos, where various researchers have investigated how unique aspects influence learning and should be designed (Merkt et al., 2011; Merkt & Schwan, 2014; Schwan & Riempp, 2004). This study aims to fill this gap in the current research literature.

2 | LITERATURE REVIEW

2.1 | Cognitive basics of learning with 360° videos

Whether instructional videos are an effective learning tool (Kay, 2012; Schmid et al., 2014; Stockwell et al., 2015) or rather ineffective (MacHardy & Pardos, 2015) always depends on the instructional methods used. For example, Guo et al. (2014) pointed out that videos with large segments are disregarded by students. In this vein, it becomes clear that boundary conditions and the design of the video are crucial for learning success (Mayer, 2021). In particular, when using 360° videos in educational settings, several processes that determine the effectiveness of learning must be discussed.

2.1.1 | Discovery learning

The use of 360° videos can be combined with approaches such as discovery learning. In these approaches, the learning materials are designed in such a way that the learners discover the content (i.e., the learning scenario) themselves under guidance from the teachers (Hammer, 1997), for instance, by running an experiment with carefully designed worksheets. Even if these approaches have been criticized for some time (Kirschner et al., 2006; Mayer, 2004), they are still very popular and intuitively appealing (Kirschner et al., 2006). Meta-analyses have revealed that enhanced and/or assisted discovery, compared with other types of instruction, improves learning outcomes (Alfieri et al., 2011). In the case of 360° videos, different forms of signaling could be used as simple forms of guidance.

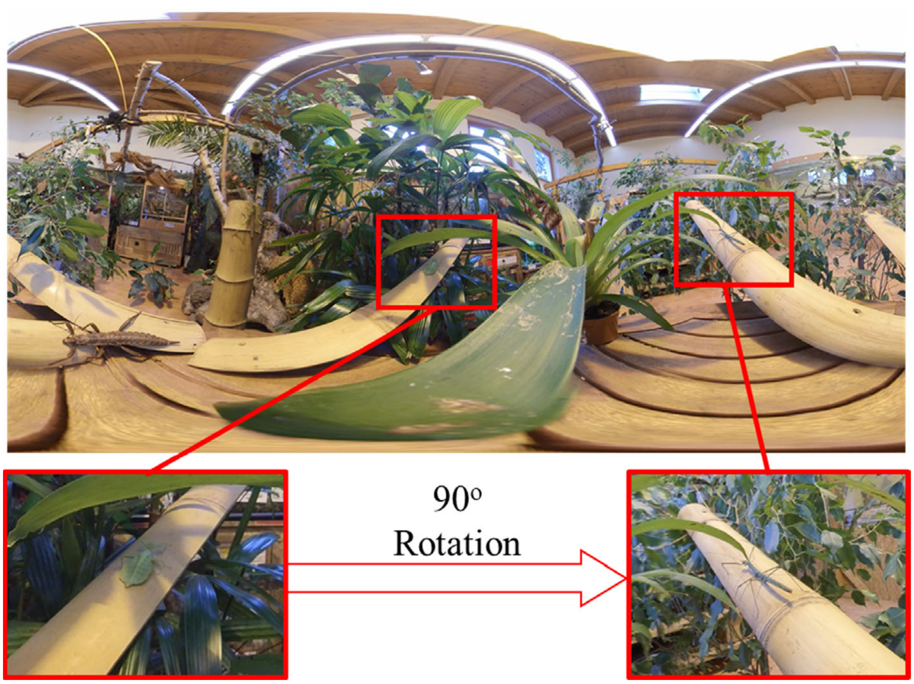

FIGURE 1 Different insects are hidden in a 360° video setting. To find them, learners have to adjust the image detail.

2.1.2 | Cognitive load

Cognitive learning theories have frequently been addressed when discussing new forms of video learning environments (Cattaneo et al., 2019). A well-established and empirically verified framework is cognitive load theory (CLT; Sweller, 1988; Sweller et al., 2019). According to CLT, cognitive resources in working memory are limited. When learners deal with a multimedia learning environment, three different types of cognitive load strain their limited working memory capacity (intrinsic, extraneous, and germane load; Paas et al., 2003; Sweller et al., 1998). First, intrinsic cognitive load (ICL) can be defined as the complexity of the learning context itself (Kalyuga, 2011). It is determined by the element interactivity of the content (the number of elements that must be processed simultaneously in the working memory) and the learner's domain-specific prior knowledge (Sweller et al., 2019). Working memory load is not only caused by the ICL, but also by a design of the learning environment. An inappropriately designed instructional format imposes an extraneous cognitive load (ECL) and suppresses learning (Paas & Sweller, 2014). To facilitate schema construction and automation, extraneous processing should ideally be avoided (de Jong, 2010). ECL is a crucial aspect when discussing the effectiveness of 360° videos. Since learners have to adjust the screen details within the video by themselves, the need for adjustment can be viewed as ECL. Furthermore, a larger field of view contains more visual information and movements that must be observed. Consequently, when learners do not know what part of the video is important and where to look, the visual load increases. This might be even more important considering the transient information (Leahy & Sweller, 2011; Sweller et al., 2011). This effect occurs when learning with media that presents information "in a form that is transient and difficult to retrieve rapidly and when required" (Wong et al., 2012, p. 449). In the context of 360° videos, the transient information effect must be given special consideration, since not only changing visual and verbal information must be maintained in the working memory during reception, it is further possible that information is not noticed. Transient information that is not in the image section currently being viewed cannot be used by the learner and considered for processing new information. Designers of instructional material should aim to minimize ECL to leave resources for germane cognitive load (GCL). GCL describes the load and resources that are allocated to schema construction and refers to active processing (i.e., mental effort; Jiang & Kalyuga, 2020). Designers of 360° videos should manage cognitive load during learning to maximize GCL, since a high GCL is an indicator of engaged learners directing their cognitive resources to the learning process (Klepsch et al., 2017).

2.1.3 | Spatial presence

As argued within the introduction, 360° videos offer the potential to experience certain situations firsthand or *feeling like actually being there*—which has been the cornerstone of the investigation of (spatial) presence (Minsky, 1980). More specifically, presence can be defined as a physiological state where the user's attention is fully captured by the mediated environment (Witmer et al., 2005) up to the point of interpreting the mediated environments as real (Ivory & Kalyanaraman, 2007). The process of perceiving presence can be described using Wirth et al.'s (2007) two-step model. First, learners must process spatial cues mediated by the virtual environment and incorporate them into a mental representation of the depicted space. This representation is described as the spatial situation model (SSM). In addition, media factors, such as features that trigger attention processes, play a crucial role. Research could demonstrate that presence might be influenced by different devices used to consume 360° videos (Rupp et al., 2019). Once different situation models have emerged, the most convincing model is unconsciously selected. When the mediated model is the selected model, the user feels presence regarding the mediated environment. Nevertheless, according to the cognitive affective model of immersive learning (Makransky & Petersen, 2021), irrelevant cognitive strains could be induced through high degrees of presence. This is in line with research on highly immersive media, such as videogames (Schrader & Bastiaens, 2012). The increased extraneous load might be related to learning from a strictly cognitive perspective. However, if motivational or metacognitive variables are considered (e.g., embodiment, interest, self-efficacy), the overall effect of presence on learning could still be positive (Makransky & Petersen, 2021). However, to our knowledge, no comparison of traditional and 360° videos regarding perceived presence and its negative or positive consequences for learning has been made to date. Thus, all potential benefits and challenges remain unverified, and a research design with a *traditional video* control group is needed.

2.2 | Signaling

The signaling, or cueing, principle refers to the finding that learning from instructional materials is enhanced when relevant elements or the organization of the material are highlighted (for reviews, see Alpizar et al., 2020; Schneider, Beege, et al., 2018; Richter et al., 2016; van Gog, 2014). In line with the transient information effect, the signaling principle can be explained by considering CLT. Signaling information supports learners by helping them recognize which information in instructional material is relevant to learning. Thus, signaling directs learners' attention to the most important learning-relevant material. Evidence for the signaling effect is provided considering eye-tracking studies, which point out that visual cues can direct the eye movements of learners to the most important information and limit the amount of time spent fixating on the less relevant areas (Jamet, 2014). In particular, in system-paced (i.e., limited time for information presentation) transient learning materials, such as 360° videos, signaling is an important instructional support (Kühl et al., 2012; Schneider, Beege et al., 2018). Studies on VR generally support the beneficial effects of signaling (Albus et al., 2021). Signaling in a virtual classroom fosters recall and enhanced GCL. Nevertheless, no effects on transfer or ECL were found (Albus et al., 2021).

These contradictions emphasize that signaling in 360° videos might be more complex than signaling in classical instructional media. Liu et al. (2021), as well as Albus and Seufert (2022), emphasized that textual and visual cues in 360° videos could reduce the imbalance in attention distribution, but there is a need for further optimization.

2.2.1 | Macrolevel signaling

Since information is distributed over the whole 360° field of view, important information can easily be overlooked (learners can choose the wrong image details). Consequently, learners also need to be told when and where to see them in a 360° learning material. The transient information effect is problematic because of (1) missing attention and limited working memory of the learner, and (2) the ability to adjust image details freely through the video also offers the possibility of missing relevant information. Following previous attempts (Jarodzka et al., 2013; Yang, 2020), one type of signaling (i.e., macrolevel signaling) reduces the negative effect of the transient information effect by directing learners' attention to the relevant field of view at the time the relevant information is presented. This might be done by, for example, spotlights that darken (Jarodzka et al., 2013) or abstract (Lokka & Çöltekin, 2016) nonrelevant areas, gestures, and verbal statements that direct attention (Sheikh et al., 2016), textual annotations (Albus et al., 2021), or inserting directional cues such as progressive arrows (Yang, 2020). These cues help adjust the image detail to the learning-relevant area of a 360° video and orientate it within the room. For example, if the lecturer talks about the specific characteristics of an animal, signals are placed around the whole 3D environment to direct the learner's attention to the animal. Since the macrostructure of the 360° video is addressed, these cues are called *macrolevel signaling*.

2.2.2 | Microlevel signaling

Based on the visual complexity of dynamic learning materials, learners might not intuitively recognize which information is relevant for the learning goal, even if the correct image detail is chosen within a 360° video. Too much information can increase cognitive load and impair performance with spatial tasks (Hegarty et al., 2012), such as learning with dynamic videos. Consequently, additional signaling techniques can be used to highlight the most important information, that is, components of a technical device or a closed system within the chosen image detail. Following previous implementations (Amadieu et al., 2011; Kühl et al., 2012), a second type of signaling might help to reduce the visual load arising from numerous objects and movements in the field of view. This classical form of signaling can be compared with applications of the signaling effect in the CLT literature (Schneider, Beege, et al., 2018). Examples of visual microlevel signaling can be found in coloring (Arslan-Ari, 2013), static pointing cues (Kriz & Hegarty, 2007), flashing (Jeung et al., 1997), or labeling (Huk et al., 2010), and this approach has already been successfully applied to traditional videos (Glaser & Schwan, 2020). For example, if the lecturer talks about the specific characteristics of an animal, signals are placed on the animal to direct the learner's attention to the specific features of the animal. Because the microstructure of the relevant image detail within the 360° video is addressed, these cues are called *microlevel signaling*.

3 | THE PRESENT EXPERIMENT

The current study aims to investigate the effect of two signaling techniques (macrolevel and microlevel signaling) on learning with 360° videos and their comparison with a traditional learning video (control group). To gain a deeper understanding of learning with this advanced technology, learning outcomes, as well as process variables, are measured. Thus, insights into cognitive load, as well as irrelevant thinking, disorientation, and presence are provided.

> **RQ1.** Does signaling within 360° videos foster learning?

As outlined, directing the attention of the learner to the relevant image detail (macrolevel signaling) as well as to the most important information within the image detail (microlevel signaling) fosters learning processes. Nevertheless, to date, these effects have not been investigated in the context of 360° videos. Concerning the discussed literature, the following hypotheses were postulated:

> **H1a.** Learners receiving a 360° video with macrolevel signaling achieve higher learning outcomes than learners receiving a 360° video without macrolevel signaling.

> **H1b.** Learners receiving a 360° video with microlevel signaling achieve higher learning outcomes than learners receiving a 360° video without microlevel signaling.

> **RQ2.** Does signaling within 360° influence cognitive load?

From the cognitive load perspective, both signaling techniques should reduce ECL since the eye movements of learners are directed to the most important information (Jamet, 2014). Consequently, GCL should be enhanced, since relevant information is processed longer and more elaborately (Amadieu et al., 2011). Thus, the following hypotheses were formulated:

> **H2a.** Learners receiving a 360° video with macrolevel signaling report a lower ECL than learners receiving a 360° video without macrolevel signaling.

> **H2b.** Learners receiving a 360° video with microlevel signaling report a lower ECL than learners receiving a 360° video without microlevel signaling.

H2c. Learners receiving a 360° video with macrolevel signaling report a higher GCL than learners receiving a 360° video without macrolevel signaling.

H2d. Learners receiving a 360° video with microlevel signaling report a higher GCL than learners receiving a 360° video without microlevel signaling.

RQ3. Does signaling within 360° influence subjective ratings?

Reducing ECL through signaling should be reflected in subjective ratings of the reception process. Since attention is guided intentionally, signaling should reduce the perception of disorientation (Karich et al., 2014). Furthermore, since learners focus more on relevant instructional information through signaling, irrelevant thinking should be reduced (Karich et al., 2014). The following hypotheses were formulated:

H3a. Learners receiving a 360° video with macrolevel signaling report lower disorientation and irrelevant thinking than learners receiving a 360° video without macrolevel signaling.

H3b. Learners receiving a 360° video with microlevel signaling report lower disorientation and irrelevant thinking than learners receiving a 360° video without microlevel signaling.

RQ4. How do macrolevel and microlevel signals interact in terms of learning processes?

The interaction effect of both signaling techniques is of particular interest. Unfortunately, no scientific studies have been carried out in this context thus far. Microlevel signaling might be beneficial for learning, but the full potential of microlevel signaling can only unfold if the learner first selects the relevant image section with the help of macrolevel signaling. Consequently, learners must know where to look first. After choosing the correct image detail, microlevel signaling helps the learner identify important information within the image detail. Thus, the fifth hypothesis was formulated:

H4. Microlevel signaling in 360° videos is more beneficial for learning when additional macrolevel signaling is provided, in contrast to a 360° video without macrolevel signaling.

The control group (classical video) will be included to compare immersive learning material with classic instructional media featuring the same content. Whereas cognitive load might be enhanced when watching 360° videos, benefits concerning guided discovery and spatial presence might at least compensate for this effect. Since no prior studies could be identified that compared 360° videos to a classical counterpart, the following research question was formulated:

RQ5. Do 360° videos promote learning in contrast to classical instructional videos?

Process variables, such as spatial presence and disorientation, will be further explored in the context of signaling within 360° videos. As discussed earlier, individual differences in perceived presence and perceived disorientation could influence cognitive load and learning outcomes. Consequently, these variables could moderate the effect of signaling on cognitive load and learning.

RQ6. Do perceived presence and disorientation moderate the effect of signaling on cognitive load and learning?

4 | METHOD

4.1 | Participants

Recent studies and meta-analyses regarding signaling have reported medium effect sizes (e.g., $g+ = .53$; Schneider, Beege, et al., 2018; $d+ = .38$; Alpizar et al., 2020). Based on that, the estimated required sample size for this experiment is based on a medium effect. According to an a priori power analysis ($f = .25$; $\alpha = .05$; $1 - \beta = .90$; 2×2 design), at least 172 participants (four groups, each with 43 participants) will be recruited for the signaling conditions. In addition, the control group will be created identically (i.e., 43 participants), leading to 215 required participants for the entire study. Fifth- to sixth-grade students will be recruited since the level of difficulty of the information in the experimental video used is adapted to 10- to 12-year-old learners. The learning material will not be part of the curriculum to ensure that students' prior knowledge is averagely low. A biology teacher was asked for advice and confirmed this level of demand. Since a low amount of prior knowledge by some participants cannot be ruled out, prior knowledge will be assessed and used as a covariate if imbalances occur. Furthermore, meta-analyses have revealed that signaling is effective for secondary school students (Schneider, Beege, et al., 2018).

Inclusion/exclusion criteria. The first prerequisite is at least average language understanding. As outlined, the level of the video is adapted to young secondary students; thus, the language used in the video is not complex. Nevertheless, considering the transient information effect, students should be able to understand the language without a problem so that working memory resources will not be additionally stressed. Students with a low level of understanding or students reporting problems during the reception will not be included in the analyses, but are still allowed to participate. For this, the teachers will be asked whether their students are not capable of the requirements of the CERF C1 level (e.g., understanding a wide range of longer and more demanding texts or conversations), and

FIGURE 2 Screenshot of the instructional video; left: adjusted image detail during the reception (signaling conditions); right: full video frame (control condition).

participants will be asked whether they had difficulties with the used language. If either is true, the participant will be excluded.

Technical problems may occur due to the reception of the experimental video. Even if the sound is controlled and the material is pretested multiple times, the use of tablets is a source of potential problems. If the image detail adjustment is not working, the video is lagging, stops, or cancels, data from the participants will be excluded from the analyses to ensure that the reception process is technically controlled among all participants. Similar to the above, participants will be asked after the experiment if anything of this sort happened. In addition, the researchers conducting the experiment will try to observe if any technical difficulties occur. Again, if either of these methods reveals issues, the participants will be excluded.

4.2 | Design

The study will apply a randomized between-group 2 × 2 design with two different versions of signaling as experimental factors, resulting in four experimental groups. In addition, a control group will be used. There will be one group without any signaling (*NO SIGNAL*), two groups including either macrolevel or microlevel signaling (*MACRO*; *MICRO*), one group including both variations of signaling (*COMBINATION*), and one group showing the original video stream without the presentation as a 360 video° (*CONTROL*). Students will be assigned to the five groups by drawing lots individually. Consequently, the sample will not be nested.

4.3 | Materials

A 360° instructional video on the topic of the visual and behavioral characteristics of animals in a zoo with a length of approximately 8 min will be used as material during the presented study. The video contains dynamic visual images of various animals, typically not included in the school curriculum, such as Shetland ponies, common marmosets, Chacoan maras, various Phasmatodea, miniature pigs, and Parma wallabies. A transcript of the spoken text can be found in Appendix A. The video was filmed with a 360° camera (*Insta 360 One X* camera on a tripod). The video material uses a resolution of 3072 × 1536 pixels with a 48 kHz stereo audio signal. Thus, relatively small equipment can be placed inside enclosures, providing a perspective that cannot typically be taken by visitors. For instance, on one occasion, the camara could be placed within a terrarium, allowing observation of the surrounding animals from up close. For the control condition, we used the original video stream without being bent into a 360° video (Figure 2).

Additional visual texts were included in the postproduction. To avoid distracting the learner from the animals, only a few words (names of the animals) were included. Furthermore, a 1174-word audio commentary provides information on different animals (e.g., their visual characteristics and behaviors). Overall, the video contains facts about the various animals without resorting to scientific terminology to ensure understandability for our participants. The goal for the learner is to memorize the visual and auditory information presented. Consequently, the secondary students receive the following instructions before watching the video: "You are now watching the instructional video. Remember to navigate through the video as we have shown. Watch the video carefully, and try to remember as much information as possible. You will answer questions about it after watching it." Signaling is implemented by adding various forms of visual cues during video editing with Adobe After Effects CS6 (Adobe, 2012).

4.3.1 | Macrolevel signaling

To implement macrolevel signaling, prior work on signaling can be used as a basis. In particular, signals that cover large image sections are used for implementation. Relying on prior research, the darkening of nonrelevant areas (Jarodzka et al., 2013), as well as the use of progressive arrows (Yang, 2020), will be used to guide the participants to the relevant image details. For example, the animals that are relevant to look at during the lecture are only present in a certain section of the image. Thus, arrows and textual notes are used to highlight that relevant visual information is located left or right from the current field of view. This might help the learner adjust their field of view to the correct image details (see Figure 3). Spotlights are another

FIGURE 3 Screenshots of macrolevel signaling through text and arrows; translated text: "You are missing something!."

FIGURE 4 Screenshots of macrolevel signaling through spotlights; left: no support; right: support.

FIGURE 5 Screenshots of microlevel signaling I; moving pattern.

nontextual form of macrolevel signaling. In this case, relevant elements are brightened up or irrelevant details are darkened (see Figure 4).

4.3.2 | Microlevel signaling

The most important information within an image detail is signaled with respect to prior work in the field of signaling in multimedia learning environments (Schneider, Beege, et al., 2018). Signals are implemented temporally congruent with the audio commentary to ensure that the relevant visual parts are signaled at the time they become relevant in the lecture. Typically, key concepts are signaled using colors or moving patterns, catching the attention of the viewer (Arslan-Ari, 2013; Jeung et al., 1997). In the experimental material, various forms of signaling are used to ensure a diversified video that still focuses on highlighting important visual information. For example, the fur structure of a horse is important in the lecture. At the time the fur is mentioned, a moving pattern highlights the spotty structure (see Figure 5). Other forms of signaling are white spots (see Figure 6) or moving black lines (see Figure 7), indicating specific areas.

4.4 | Measures

4.4.1 | Learning

To assess prior knowledge, five open-answer questions will be presented. The questions covered the spectrum of knowledge that was later included in the learning text. Students will be able to get 10 points per open-answer question. An example is, "What do you know about mini-appaloosas?" Students will get a point when they mention a fact that will be explicitly part of the experimental video. The interclass correlation coefficients of two independent raters will be conducted to ensure interrater reliability.

FIGURE 6 Screenshots of microlevel signaling II; left: nonsignaled; right: white spots.

FIGURE 7 Screenshots of microlevel signaling III; from left to right, moving black line.

A retention and transfer test will be implemented to adequately assess learning performance. Retention can be defined as remembering or reproducing information that was presented in the instructional videos, and transfer refers to applying knowledge to solve novel problems that were not explicitly presented in the learning material (Mayer, 2014). The retention test, as well as the transfer questionnaire, covers a wide range of signaled and nonsignaled information from the video. Again, a biology teacher reviewed the learning scales and confirmed that the learning outcomes were adequately assessed. After finishing the data collection, reliability scores will be obtained.

Retention will be measured with 15 multiple-choice questions (e.g., "Which fur variations do mini-appaloosas have?"). Students receive points for selecting correct answers and not selecting incorrect answers. Students are thus able to get up to four points per question and a maximum of 60 points in the retention test.

Transfer will be measured with 15 open-answer questions (e.g., "Why are insects, which can camouflage themselves, nocturnal?"). The open questions must be answered with short sentences or bullet points. When the question is answered correctly, the students gain up to two points. Overall, students can gain a maximum of 30 points from the transfer questionnaire. To ensure that interrater reliability is given, the intraclass correlation coefficients of two independent raters will be conducted.

4.4.2 | Cognitive load

Cognitive load will be measured using a questionnaire from Klepsch et al. (2017). Two items measure ICL (e.g., "This task was very complex"), and two items measure GCL (e.g., "My point while dealing with the task was to understand everything correctly"). Three items measure ECL (e.g., "During this task, it was exhausting to find the important information"). The participants rate the items on a 7-point Likert scale ranging from 1 (absolutely wrong) to 7 (absolutely correct). Although the limitations of subjective self-report measures of cognitive processes are currently discussed in the literature (Ayres, 2018), they are successfully applied within different types of media in educational psychology research (Nebel et al., 2017, Schneider, Nebel, et al., 2018). In addition, compared with physiological measures, they demonstrate higher validity (Ayres et al., 2021).

4.4.3 | Disorientation

The disorientation scale from Ahuja and Webster (2001) will be used. The scale consists of seven items (e.g., "I didn't know how to get to my desired location"). The participants will rate the items on a 7-point Likert scale ranging from 1 (does not apply at all) to 7 (applies completely).

4.4.4 | Presence

To address presence, relevant subscales from the MEC Spatial Presence Questionnaire (Wirth et al., 2008) will be used. In order to measure potential differences between the participants in their capability to imagine the presented environment, visual–spatial imagery (VSI) will be measured with eight items (e.g., "When I read, I often have a precisely detailed image of the described surroundings in my mind's eye"). To access the imagined situation model, the SSM subscale with eight items (e.g., "I had a precise idea of the spatial surroundings presented in the video") will be used. Finally, to address whether the participants perceive spatial presence, the spatial presence self-location (SPSL) scale providing eight items (e.g., "I felt as though I was physically present in the environment of the video") will be used. The participants will rate all items on a 5-point Likert scale ranging from 1 (not at all) to 5 (very much).

4.4.5 | Demographics

Finally, demographic variables will be assessed. Age, as well as gender, will be assessed with self-report questions. In particular, gender might play an important role in the experiment. According to prior research, there are potential gender differences concerning STEM education (Wang & Degol, 2017) and spatial ability (Yuan et al., 2019), particularly when using dynamic visualizations (Castro-Alonso et al., 2019). Consequently, gender will be added as a covariate if significant imbalances occur. Furthermore, prior experiences with VR and 360° videos, as well as the students' mother tongues, will be assessed with self-report questions.

4.5 | Procedure

Before the experiment takes place, the parents of the children will be informed about the nature of the experiment, data management policies, and potential risks. They will receive an information and consent form, and only participants with a signed form will be able to participate. The experiment will take place in classrooms to ensure external validity. Furthermore, an investigator will be constantly present to assist if any help seems necessary. In the beginning, the participants will be greeted and informed about the upcoming task in line with ethical guidelines (American Psychological Association, 2016). Afterward, they will be assigned to the experimental groups by drawing lots, and the pretest questionnaire will be filled out. With this, prior knowledge will be collected. This first segment will take 10 min. To minimize potential dropouts because of technical difficulties, the questionnaires will be handed out in paper format. For this initial questionnaire and all other measures, complete anonymization will ensure that no data can be attributed to a specific participant. Finally, a 360° picture unrelated to the experimental material will be presented. Using this method, the participants will be instructed how to navigate through 360° material on the device and how to practice the image detail adjustments necessary for the following video task. This segment, which takes approximately 2 min, will be followed by the experimental phase. Each participant will receive a video matching their assigned experimental group. Participants will be told to watch the video carefully because questions will be asked afterwards. They will watch the video on *IdeaPad Miix 320* tablets with a 10.1″ display offering a 1920 × 1200 pixel resolution while wearing Sharkoon ER1 headphones. The image details will be intuitively adjustable by the participants using the touchscreen. The participants will be able to watch the video once (system paced) without the possibility of pause or to skip/rewatch passages. After approximately 10 min, the video phase is finished, and the participants will receive the posttest questionnaires, collecting data on retention knowledge, transfer knowledge, image details, cognitive load, disorientation, presence, and demographics. This will take about 20 min. Afterward, they will be informed about the nature of the manipulation and the purpose of the questionnaires, and they will be dismissed. Altogether, the experiment will last approximately 45 min and will be conducted within one regular lesson. To ensure that this time frame is adequate and that, for example, test fatigue does not occur, a short pretest will be carried out before the main experiment. Based on the results, the time slots will be adjusted. After the experimental sessions, the paper questionnaires will be digitalized, and the original paper documents will be destroyed and adequately disposed of.

5 | DATA ANALYSIS

Before conducting the analyses concerning our hypotheses, an outlier analysis (Grubbs, 1969) will be conducted to ensure that no extreme outliers or artificial result patterns are included in the analysis. Reliability analyses will be conducted afterwards to determine whether all items can be used to conduct sum scores, as well as mean values of all scales. Because of the ongoing criticism of Cronbach's α (for an overview, see McNeish, 2018), the coefficient McDonald's ω (McDonald, 1999) was chosen to calculate reliability estimates for all measures. The interpretation of the level of reliability is identical to that of Cronbach's α (Gliem & Gliem, 2003). In this vein, good reliability will be assumed if $\omega > .70$. If reliability is insufficient, items will be excluded to strengthen reliability. If this is not possible, the scale will still be included in the calculations, but the results will be discussed and put into perspective, considering the restricted reliability.

Furthermore, demographic data, as well as the prior knowledge of the participants, will be analyzed to investigate whether covariates have to be included in following the analyses. Analyses of variance (ANOVAs) will be conducted for metric variables (age, prior knowledge, class level, language skills), and χ^2 tests will be conducted for nominal variables (gender, visual impairments) to detect differences between the experimental groups. For all analyses, the convention of $\alpha < .05$ will be adapted. If prior knowledge or demographic variables differ between the experimental conditions, these variables will be used as covariates in further analyses.

To investigate the postulated research questions and hypotheses, multivariate analyses of [co]variance (MAN[C]OVAs) and univariate analyses of [co]variance (AN[C]OVAs) will be conducted. As mentioned, covariates will only be included if demographic variables or prior knowledge differ between conditions. Concerning RQ1, macrolevel signaling and microlevel signaling will be included as independent variables. Retention, as well as transfer performance, will be included as dependent variables. Again, the convention of $\alpha < .05$ will be adapted. Predefined test assumptions will be considered. Normal distribution will be investigated using the Shapiro–Wilk test (Shapiro & Wilk, 1965). Variance homogeneity will be investigated using Box's M test for MANOVAs (Box, 1949) and Levene's test for homogeneity for ANOVAs (Levene, 1960). If variance homogeneity is not given, Welch's corrected ANOVAs will be conducted instead of "standard" Fisher's ANOVAs, since Welch's ANOVAs are robust against prerequisite violations (Lix et al., 1996). For the main analyses, the effect size of partial eta squared (η_p^2) will be calculated. Conventions for the interpretation of η_p^2 will be adapted from Pierce et al. (2004): (1) small effect: $\eta_p^2 > .01$; (2) medium effect: $\eta_p^2 > .06$; (3) large effect: $\eta_p^2 > .14$. First, MANOVA results will be interpreted, and if the omnibus MANOVA shows significant results, follow-up ANOVAs will be conducted to obtain deeper insights into dependent variables separately. This procedure will be adapted to the analyses of RQ2 and RQ3. These will differ only concerning the dependent variable tables that will be used (RQ2: cognitive load facets; RQ3: disorientation, usability, irrelevant thinking). Since AN[C]OVAs report interaction effects, RQ4 will be automatically investigated by conducting the outlined analyses.

To address RQ5, omnibus AN[C]OVAs will be conducted with all five experimental groups (NO SIGNAL; MACRO; MICRO; COMBINATION; CONTROL) as independent variables and learning scores as dependent variables. Bonferroni–Holm corrected posttests (Holm, 1979) will determine how classical instructional videos perform compared with 360° videos.

To address RQ6, several moderation analyses will be conducted. Moderator analyses will be carried out using PROCESS (Hayes, 2017) with a bootstrap sample of $N = 5000$. For the analyses of VSI, the SSM, SPSL, and individual models will be used. For this, signaling techniques will be included as independent variables, learning outcomes as dependent variables, and VSI, SSM, or SPSL as potential moderators. This process will be repeated ECL as a dependent variable.

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CONFLICT OF INTEREST

I declare that I and all co-authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study will be available from the corresponding author upon reasonable request.

PATIENT CONSENT STATEMENT AND PERMISSION TO REPRODUCE MATERIAL

No patients or reproduced material included.

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APPENDIX A: TRANSCRIPT OF THE VOICEOVER OF THE INSTRUCTIONAL VIDEO

A.1 | Original transcript (German)

A.1.1. | Startbildschirm

Willkommen im "Zoo der Minis" in Aue. Wir nehmen dich mit auf unseren Rundgang und stellen dir ein paar der kleinsten tierischen Bewohner unserer Erde vor.

A.1.2. | Mini-Appaloosa

Wir befinden uns hier im Gehege der Mini-Pferde. Neben den Shetlandponys gibt es hier auch ein besonders kleines, geschecktes Pony, das Mini-Appaloosa. Diese Rasse ist mit dem Shetlandpony verwandt und wird gerade einmal bis zu einem Meter groß. Zum Vergleich, das Größte Pferd, das Shire Horse ist 2.19 Meter groß. Bei Pferden wir die Größe als Stockmaß bezeichnet. Damit ist die Höhe bis zum Widerrist, also dem Übergang vom Hals zur Rückenpartie gemeint. Dies Größe ist besonders während der Körung wichtig. Damit wird die Zuchtprüfung bezeichnet, bei der festgelegt wird ob das Pferd den Zuchtstandards entspricht und es zur weiteren Zucht verwendet werden kann. Wann und wo sie entstanden ist, weiß man nicht genau. Die Zucht der Mini-Appaloosa begann jedoch in den Niederlanden. Hier wurden verschiedene Rassen, wie Falabellas und amerikanische Miniaturpferde, gekreuzt. Die meisten Mini-Appaloosa sind Tigerschecken. Dabei handelt es sich entweder um eng aneinander liegende Farbgebung, die weniger Flecken, sondern mehr linienähnlich angeordnet sind, wie es bei Tigern der Fall ist und weshalb diese Zeichnung auch Tigerscheckung genannt wird. Eine andere zulässige Variante sind Flecken. Diese unterscheiden sich von klassischen Schecken-Pferden durch unregelmäßig verlaufende Fleckränder, die oftmals zackig und immer unregelmäßig verlaufen. Vergleichbar ist/sind die Fleckenbildung/—formen mit wirr verlaufenden Pigmentstörungen bei menschlicher Haut. Es gibt aber auch seltene variationen, bei denen die Zeichnung erst ab der Kruppe beginnt. Nebenihrer ungewöhnlichen Zeichnung fallen die Tiere auch durch ihr besonderes Temperament auf. Die kleinen Pferde sind intelligent, sensibel und anhänglich. Sie gelten als ausgeglichen und weniger eigensinnig als Shetlandponys.

Übrigens, Mini-Appaloosa eignen sich besonders gut als Pony für Kinder.

A.1.3. | Weißbüschelaffen und Zwergmaras

In diesem Gehege ist richtig was los. Hier wohnen die Weißbüschelaffen zusammen mit den Zwergmaras. Die Äffchen zählen mit einer Größe von bis zu 25 cm zu den kleinsten Vertretern unter den Affen. Neben ihrer geringen Körpergröße fallen sie besonders durch ihren langen, grau-schwarz geringelten Schwanz sowie durch ihre weißen Haarbüschel an den Ohren auf. Das Gesicht ist hell gefärbt, spärlich behaart und auf der Stirn befindet sich ein weißer Fleck. Ihr Lebensraum sind Wälder, wobei sie in verschiedenen Waldtypen vorkommen können. So sind sie in der steppenartigen Caatinga ebenso zu finden wie in den feuchten atlantischen Küstenwäldern. Wie alle Marmosetten—die Obergattung dieser Affenart—sind sie dank der spezialisierten Zähne in der Lage, Löcher in die Baumrinde zu nagen, um an die Baumsäfte zu gelangen. Diese spezialisierte Ernährung ermöglicht es ihnen, mit kleinen Lebensräumen auszukommen und vermindert die Nahrungskonkurrenz zu größeren, in stärkerem Ausmaß von Früchten abhängigen Primatenarten.

Der Zwergmara gehört zur Familie der Meerschweinchen und wird auf Grund seines Aussehens und der Fortbewegungsweise auch kleiner Pampahase genannt. Er ähnelt einem Hasen, erreicht eine Kopfrumpflänge von 45 bis 50 cm und wird etwa 4 kg schwer. Als Bewohner der Gran Chaco in Südamerika bevorzugt die Art trockene Flachlandgebiete mit einer Vegetation aus Dornbüschen.

A.1.4. | Insekten

Wir befinden uns jetzt im Krabbelzoo. Wenn du genau hinschaust findest du hier die Meister der Tarnung. Nimm dir ein wenig Zeit und versuche vier verschiedene Insekten zu entdecken.

Na, hast du alle gefunden? Siehst du das Tier, was aussieht wie ein kleiner Zweig und in einem tollen türkis leuchtet? Das ist eine türkise Stabschrecke. Sie gehört zu den Gespenstschrecken und kann mit bis zu 20 cm recht groß werden. Sehr wichtig für die Haltung ist eine gute Belüftung. Die Tiere stammen aus einer eher trockenen Umgebung in Madagaskar. In einem feuchten Habitat bzw. bei Staunässe kommen sie nicht gut zurecht.

Die braunfarbige Dorngespenstschrecke ist auf einem Baumstamm kaum zu entdecken. Sie wird aufgrund ihres sehr festen Exoskelettes auch Panzerschrecke genannt und kann bei Gefahr sehr aggressiv werden. Sie hält sich tagsüber in Sträuchern nahe dem Boden auf und ist vorwiegend nachtaktiv. Die Weibchen arata sind größer und insbesondere am Abdomen breiter als die Männchen. Sie haben einen deutlich erkennbaren Legeapparat (Ovipositor) und werden mit etwa 140 bis 150 Millimeter Länge größer als die etwa 120 Millimeter langen Männchen. Diese haben im Gegensatz dazu deutlich massigere Hinterschenkel.

Auf dem Bambus sitzt eine südamerikanische Riesenheuschrecke. Die Weibchen können zwischen acht und zehn cm groß werden. Die Männchen hingegen werden lediglich zwischen sieben und acht cm groß. Charakteristisch für diese Art ist das grüne Nackenschild. Durch ihre, im Verhältnis zur Körpergröße, recht kurzen Fühler, zählt sie zu den Kurzfühlerschrecken. Trotzdem gilt sie als die größte Heuschreckenart der Welt. An ihren Hinterbeinen befinden sich gewaltig aussehende Stachel mit denen sie sich, durch Treten, gegen Feinde verteidigen kann.

Das vierte Insekt ist das Wandelnde Blatt. Es ist in Asien beheimatet und lebt dort vor allem auf Sträuchern. Der Körper ist bei beiden Geschlechtern, genau wie die Beine auch, an den Seiten von einem dünnen braunen Band umrandet. Sie sind durch einen horizontal blattartig verbreiterten Körper charakterisiert, der diesen als

Laubblatt tarnt—die Mimese. Auch die Beine sind durch blattartige Verbreiterungen, die sogenannten Loben, optimal an diese Blattmimese angepasst. Die ahmen deren Blätter nicht nur durch ihr Äußeres nach, sondern auch in ihrem Verhalten. Die Tiere sind nachtaktiv, tagsüber verharren sie stundenlang völlig regungslos. Bei Störung imitieren sie durch schaukelnde Bewegungen ein sich im Wind bewegendes Blatt und tarnen sich so vor möglichen Fressfeinden.

A.1.5. | Mini-Schweine

Mini-Schweine, auf Englisch auch "mini pigs" genannt, werden als Haustiere immer beliebter. Einst für Versuchszwecke klein gezüchtet, erobern sie heute immer mehr die Herzen der Tierhalter.

Die Schweine sind sehr intelligent und schließen sich eng dem Menschen an. Sie sollen jedoch nicht ausschließlich in der Wohnung gehalten werden, da sie viel Auslauf benötigen. Als gesellige Tiere die normalerweise in Rotten leben brauchen sie unbedingt die Gesellschaft von Artgenossen. Minischweine schnüffeln liebend gerne den Boden ab und können Essbares riechen, das sich in sechzig Zentimeter Tiefe im Erdboden befindet. Aufgrund ihrer enormen olfaktorischen Wahrnehmungen können sie den menschlichen Geruch auf eine Entfernung von dreihundert Metern riechen. Schweine werden als schmutzig bezeichnet, dabei sind sie alles andere als das. Sie suhlen sich zwar gerne im Schlamm, doch das ist ihre Art von Körperpflege, denn dadurch entfernen sie Ungeziefer von ihrem Körper.

Ansonsten sind Schweine eher saubere Tiere, die beispielsweise nur eine Stallecke als Toilette nutzen—wenn man ihnen ausreichend Platz bereitstellt.

A.1.6. | Parma-Känguru

Die scheuen Bewohner dieses Geheges sind die Parma-Kängurus—oder auch Parmawallabys. Sie galten mehr als ein halbes Jahrhundert lang als ausgestorben und wurden erst 1965 wieder entdeckt. Die kleinsten Vertreter der Kängurus besitzen ein rötlich bis grau-braun gefärbtes Fell. Sie haben weiße Brust- und Kehlregionen und einen dunklen Rückenstreifen. Die Hinterbeine sind deutlich länger und kräftiger als die Vorderbeine. Sowohl Weibchen als Männchen auch besitzen einen Beutel. Sie erreichen eine Kopfrumpflänge von 45 bis 53 Zentimetern und eine Schwanzlänge von 40 bis 55. Sie leben in der Regel einzelgängerisch, finden sich aber manchmal zu kurzlebigen Gruppen ohne ausgeprägte Sozialstruktur zusammen. Wie bei den meisten Känguruarten ist kein Territorialverhalten ausgeprägt. Parmakängurus sind Pflanzenfresser, die sich von Gräsern und Kräutern ernähren.

A.1.7. | Abspann

Möchtest du noch mehr der kleinsten Bewohner unserer Erde kennenlernen? Dann schau doch mal im "Zoo der Minis" vorbei.

A.2 | Translated transcript (English)

A.2.1. | Start screen

Welcome to the "Zoo of the Minis" in Aue. We'll take you on our tour and introduce you to a few of the smallest animal inhabitants on our planet.

A.2.2. | Mini-Appaloosa

We are here in the enclosure of the mini horses. In addition to the Shetland ponies, there is also a particularly small, pied pony, the Mini-Appaloosa. This breed is related to the Shetland pony and grows to just 1 m tall. For comparison, the largest horse, the Shire Horse is 2.19 m tall. The height of a horse is called its stature. This is the height to the withers, the transition from the neck to the back. This size is especially important during the licensing. This is the breeding test that determines whether the horse meets the breeding standards and can be used for further breeding. It is not known exactly when and where it originated. However, the breeding of the Mini-Appaloosa began in the Netherlands. Here, different breeds, such as Falabellas and American Miniature Horses, were crossed. Most of the Mini-Appaloosa are tiger pinto. These are either closely spaced colorings that are less spots and more line-like, as is the case with tigers, which is why this pattern is also called tiger check. Another permissible variation is patches. These differ from classic pinto horses by irregularly running spotted edges, often jagged and always irregular. The spot formation/shapes is/are comparable with confused pigment disorders in human skin. But there are also rare variations, where the pattern starts only from the croup. In addition to their unusual markings, the animals also stand out for their special temperament. The small horses are intelligent, sensitive, and affectionate. They are considered balanced and less stubborn than Shetland ponies.

By the way, Mini-Appaloosa are especially suitable as ponies for children.

A.2.3. | White-tufted monkeys and dwarf maras

This enclosure is a hive of activity. Here live the white-tufted monkeys together with the dwarf maras. With a size of up to 25 cm, the monkeys are among the smallest representatives among the monkeys. In addition to their small body size, they are especially noticeable for their long, gray-black curled tail and the white tufts of hair on their ears. The face is brightly colored, sparsely haired and there is a white spot on the forehead. Their habitat is forests, and they can be found in different types of forests. Thus, they are found in the steppe-like caatinga as well as in the humid Atlantic coastal forests. Like all marmosets—the parent genus of this monkey species—their specialized teeth enable them to gnaw holes in tree bark to access tree sap. This specialized diet allows them to make do with small habitats and reduces food competition with larger primate species that depend more heavily on fruit.

The pygmy mara is a member of the guinea pig family and is also called the small pampas hare because of its appearance and method of locomotion. It resembles a hare, reaches a head trunk length of 45–50 cm and weighs about 4 kg. A resident of the Gran Chaco in South America, the species prefers dry lowland areas with vegetation of thorn bushes.

A.2.4. | Insects

We are now in the crawling zoo. If you look closely, you will find the masters of camouflage here. Take a little time and try to spot four different insects.

Did you find them all? Do you see the animal that looks like a small twig and glows in a great turquoise color? That is a turquoise stick insect. It belongs to the ghost insects and can become quite large with up to 20 cm. Very important for the keeping is a good ventilation. The animals come from a rather dry environment in Madagascar. In a humid habitat or in waterlogging they do not do well.

The brown-colored thorny insect is hard to spot on a tree trunk. It is also called an armored cricket because of its very strong exoskeleton and can become very aggressive when threatened. It stays in shrubs near the ground during the day and is primarily nocturnal. Females arata are larger and broader than males, especially on the abdomen. They have a clearly visible ovipositor and, at about 140–150 mm in length, grow larger than the males, which are about 120 mm long. The latter, in contrast, have much bulkier hind legs.

A South American giant grasshopper perches on the bamboo. The females can grow between 8 and 10 cm. The males, on the other hand, only grow between 7 and 8 cm. Characteristic for this species is the green neck shield. Due to its short antennae in relation to its body size, it belongs to the short antennae grasshoppers. Nevertheless, it is considered the largest grasshopper species in the world. On its hind legs there are huge looking spines with which it can defend itself against enemies by kicking.

The fourth insect is the walking leaf. It is native to Asia and lives there mainly on shrubs. The body of both sexes, just like the legs, is bordered on the sides by a thin brown band. They are characterized by a horizontally leaf-like widened body, which disguises it as a deciduous leaf—the mimesis. The legs are also optimally adapted to this leaf mimesis by leaf-like broadenings, the so-called lobes. The mimic their leaves not only by their appearance, but also in their behavior. The animals are nocturnal, during the day they remain completely motionless for hours. When disturbed, they imitate a leaf moving in the wind by rocking movements, thus camouflaging themselves from possible predators.

A.2.5. | Mini-pigs

Mini-pigs, also known as “mini pigs” in English, are becoming increasingly popular as pets. Once bred small for experimental purposes, they are now increasingly winning the hearts of pet owners.

The pigs are very intelligent and bond closely with humans. However, they should not be kept exclusively indoors, as they need plenty of exercise. As social animals that usually live in rods, they absolutely need the company of conspecifics. Mini-pigs love to sniff the ground and can smell edibles that are 60 cm deep in the soil. Because of their tremendous olfactory perceptions, they can smell human odor at a distance of 300 m. Pigs are called dirty, yet they are anything but. They do like to wallow in mud, but this is their way of personal hygiene, as it removes vermin from their bodies.

Otherwise, pigs tend to be clean animals, using only one corner of the barn as a toilet, for example—if you provide them with enough space.

A.2.6. | Parma Kangaroo

The shy inhabitants of this enclosure are the Parma kangaroos—or Parma wallabies. They were considered extinct for more than half a century and were only rediscovered in 1965. The smallest representatives of the kangaroos have a reddish to gray-brown colored fur. They have white chest and throat regions and a dark dorsal stripe. The hind legs are significantly longer and stronger than the front legs. Both females and males also possess a pouch. They reach a head trunk length of 45–53 cm and a tail length of 40–55. They generally live solitary lives, but sometimes congregate into short-lived groups without a distinct social structure. As with most kangaroo species, territorial behavior is not pronounced. Parm kangaroos are herbivores, feeding on grasses and forbs.

A.2.7. | Credits

Want to learn even more about the smallest inhabitants of our planet? Then take a look at the “Zoo of the Minis.”