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Comparing the effects of mobile computers and traditional approaches in environmental education

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ABSTRACT

Environmental education and computers? That was traditionally seen as an antagonism. But environmental educators who compete for attention and face new challenges in an age of mobile devices, have begun to explore the opportunities that mobile computers may offer in supporting environmental learning experiences. This study investigates the impact of a mobile guide system on different parameters of environmental literacy in comparison to traditional instruments of environmental education (i.e. brochure, human guide). In a field experiment at a floodplain conservation site, 185 school children and 76 adults participated in a guided tour using different media. Despite the novelty of mobile devices and usability issues associated with the prototype mobile nature guide, participants using the computer-assisted medium achieved similar results concerning environmental literacy components. The computer as mobile guide can lead to an increase in environmental knowledge and in case of the children it can increase their motivation to engage in environmental education activities.

1. Introduction

In recent years educators have begun to consider mobile learning (m-learning) with the prospect of extending the realm of computer-mediated education to learning situations outside of traditional educational settings (Uzunboylu, Cavus, & Ercag, 2009). There have been a number of studies investigating the potential of m-learning in disciplines such as science learning that commonly take place in informal settings such as museums (Hsi, 2003; Rogers, Connelly, Hazlewood, & Tedesco, 2009). Even more so than science learning, it is the field of environmental education (EE) that heavily depends on direct experiences of natural phenomena outside the classroom. However, many environmental educators have considered the application of computer-based instruments in EE as ambiguous (Shultis, 2001). The use of the computer is traditionally seen as an antagonism to the experience of nature, especially since it has so far kept the participant from directly experiencing the natural environment (Apel & Wolf, 2005; Shultis, 2001). From this perspective, computer-mediated education may contribute to one of today's fundamental challenges for environmental education – the alienation from nature (Brämer, 2003; Van Velsor, 2004). Still, in search for novel methodologies to confront this challenge, environmental educators have become aware of the high interest in new technologies that can be observed among young people in particular (Apel & Wolf, 2005; Van Velsor, 2004). Consequently, there has been extra encouragement to add computer-based media to EE methodologies (Apel & Wolf, 2005). A variety of approaches can be found in the literature (Spicer & Stratford, 2001; Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005) but they are mostly based on virtual environments of different degrees of immersion and Spicer and Stratford (2001) stress, that these virtual environments cannot replace traditional field trips. Mobile devices, on the other hand, hold a variety of features that can help to pair the benefits of computer-mediated learning with direct nature experience. Studies like the ones presented by Rogers et al. (2009) show that handhelds can accompany the learner into the field and can at the same time scaffold exploratory activities, for instance by enabling students to sense and record aspects of the local environment, while giving the opportunity for taking electronic notes and at the same time draw upon a variety of digital resources and representations. Further, they can assist the educator in guiding the participants and monitoring their progress (Abe et al., 2005).

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It has been the objective of this study to evaluate if mobile learning systems can indeed serve as an effective instrument in environmental education activities in order to reconcile direct experience and computer-mediated education. While much of the related work focuses on technical feasibility and general user satisfaction, this paper will present a field experiment investigating the impact of a mobile learning device on different parameters of environmental literacy in comparison to traditional EE instruments. For the handheld information systems the mobile guide concept (Baus, Cheverst, & Kray, 2005) was selected as a technological foundation. It has already been employed in environmental tourism projects (Dias, Beinat, Rhin, Haller, & Scholten, 2004) and due to the aspect of context awareness it also appears suitable for deployment in environmental education (Düpmeier & Ruchter, 2004). In this study a mobile guide system was employed that has been specifically designed to assist learners during an environmental education intervention. This Mobile Nature Guide (MobiNaG) has been developed in a joint project of the Karlsruhe Institute of Technology (KIT), and the Naturschutzzentrum Karlsruhe-Rappenwört. As an environmental education institution and visitor center to a floodplain conservation area along the Rhine river, the Naturschutzzentrum Karlsruhe-Rappenwört served as an ideal test bed for the prototyping and evaluation of MobiNaG. Overall, the new context-aware mobile application, shall be employed as an on-site addition to a public environmental information systems of the State of Baden-Württemberg.

2. Materials and methods

2.1. EE intervention

A guided nature tour was used during the study as an EE intervention. It was conducted at the flood-plain conservation area, chosen as a test site, and was designed in collaboration with the Naturschutzzentrum Karlsruhe-Rappenwört, a center for conservation and environmental education on site. The intervention materials were created based on environmental interpretation principles proposed by Tilden (1957), Ham (1992). The resulting tour, titled "Wooden Helpers", guided the visitors along an easily accessible 1.5 km trail. At each of the seven stations the visitors were presented with a brief text and images, explaining which functions trees fulfill in an ecosystem and providing insights on the services they perform for man kind. The intervention went beyond the transfer of environmental information and incorporated constructive elements to foster direct experience with the interpreted natural phenomena.

2.1.1. Guide media

This study did not focus on the effectiveness of the content of the intervention itself, though. The treatments in the study design represent three different interpretive media employed to administer the tour with the aim to determine differences in their effectiveness in supporting the achievement of EE goals.

One treatment group was guided by the MobiNaG prototype. These participants were equipped with the mobile guide application running on a Pocket PC-based Personal Digital Assistant (PDA) (here a T-Mobile MDAII or a HP iPaq 5450) (see Fig. 1). The PDA was connected to an external GPS receiver (here Rikaline™ GPS-6031-X7) via Bluetooth. The deployed prototype systems provided the user with a "navigation service", displaying a map of the natural area as well as the current position of the user (see Fig. 2). The route to be followed was highlighted and the system tracked the path taken by the user. The texts and images about the trees and related activities were presented automatically as location-based information upon arrival at the points of interest (i.e. stations) by a "tour service". The technical design including IT-architecture and issues related to its implementation are discussed in detail in Düpmeier and Ruchter (2004), Patalaviciute, Düpmeier, Freckmann, and Ruchter (2005).

The second treatment group used a paper-based guidebook, which was realized as a booklet containing 17 pages of text and color images as well as a foldout paper map of the area. The route for the tour was highlighted and the map included references to the stations in the form of a photograph as well as title and page reference.

Participants of both interpretive media groups had to read the presented texts themselves. Usually the person carrying the device or the booklet had to read the text out loud for the rest of the group. With respect to navigating along the predefined route, it should be mentioned, that neither stations nor intersections were equipped with any signage related to this tour. While the groups using the brochure had to rely on the map and the pictures of the respective trees, the groups using the mobile guide system were notified by an audio signal upon arrival at the vicinity of a station (i.e. penetrating a 10–15 m radius around a station). The audio signal was accompanied by a message box announcing the station and allowing the user to view more detailed location-based information (see Fig. 2). In accordance with

Fig. 1. MobiNaG prototype system used by children during intervention.

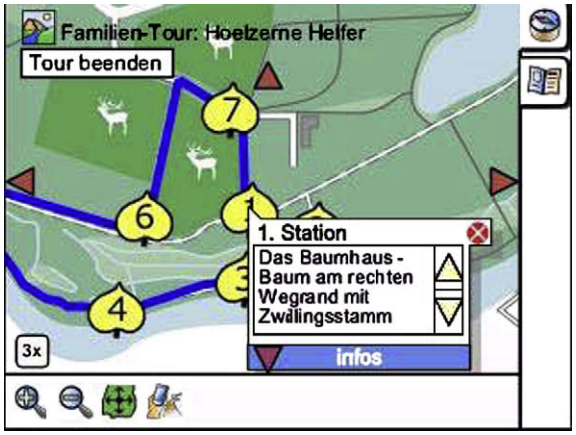

Fig. 2. Presentation of route and stations by the Navigator service.

Table 1
Basic demographics of children as assigned to media groups. Types of school corresponding to German 3-track school system: basic="Hauptschule", others="Realschule + gemeinsame Orientierungsstufe", advanced="Gymnasium".

Media groups	No. of subjects	% of all children	% of female children	Average age	Elementary school (%)	Advanced track (%)	Basic track (%)	Others (%)
MobiNaG	59	31.9	45.8	11.2	16.9	27.1	30.5	25.4
Brochure	59	31.9	45.8	11.1	22.0	16.9	30.5	30.5
Human guide	67	36.2	53.7	11.0	25.4	14.9	29.9	29.9

the paper map the mobile device did not provide additional navigational cues at intersections. It should also be pointed out that neither of the two groups received training regarding the usage of the guide media prior to participation.

The third treatment group was guided by a person. All sets of one target group were always attended by the same guide in order to keep the variation between sessions low (Bogner, 1998a). In contrast to the self-guided groups, the human guide groups did not have to worry about navigational aspects due to the guidance by the educator. The human interpreter gave oral presentations at each station, based on the same textual content used in the other media. Giving personal-based tours under realistic conditions also meant that for organizational reasons the sets guided by the human guide commonly included more participants (i.e. 2–3 families or 9–12 students) than those assisted by self-guided media.

2.2. Participants

The evaluation was conducted with children and adults. Children participated either together with their parents as part of family groups or as members of school classes. Both target groups were identified during a prior front-end evaluation (Düpmeier & Ruchter, 2004). Recruitment took place via an information leaflet or articles in a newspaper and on the web. Children of family groups and students received the same questionnaire specifically designed for their age group and were consequently combined to one group (i.e. children) for the analysis. Accordingly, parents were served a questionnaire for adults.

2.2.1. Children

A total number of 185 children took part in the study. As is displayed in Table 1, the children were essentially evenly dispersed among the three guide media (with only a slight excess of participants in the human guide group). The same is true for the gender distribution. In all groups the participating children were on average 11 years old. As a further demographic attribute the school form that the children attended was assessed during the pretest. Approximately one quarter of the participants still attended elementary school. The secondary school children where further attributed to different school tracks that represent the three tier German school system. In all of the media groups children from the advanced, medium (i.e. others) and basic track schools were fairly evenly distributed.

2.2.2. Adults

Overall 76 adults were engaged in the study. Table 2 shows that of these adults about 40% were assigned to the human guide group while the rest was close to evenly distributed between the other media groups. The gender was basically evenly distributed in all groups, except for a slight excess of women (58%) in the human guide group. With respect to the level of education of the adult participants, it should be noted, that in the brochure group only about one third had an academic education. Whereas in the mobile and human guide group the fraction with an academic education included 58% of the group members. Table 3 indicates, that in each of the media groups the majority of adults was in their 40 s, followed closely by those in their 30 s. Since only a small fraction of max. two people per media group was older than 50 years, these participants were merged with the 40–50 years age group for the analysis.

Table 2
Basic demographics of adults assigned to media groups.

Media groups	No. of subjects	% of all adults	% of female adults	With academic education (%)
MobiNaG	24	31.6	50.0	58.3
Brochure	21	27.6	52.4	33.3
Human guide	31	40.8	58.1	58.1

Table 3
Age of adults assigned to media groups.

Media groups	30–40	40–50	50–60
MobiNaG	9	13	2
Brochure	8	11	2
Human guide	11	19	1

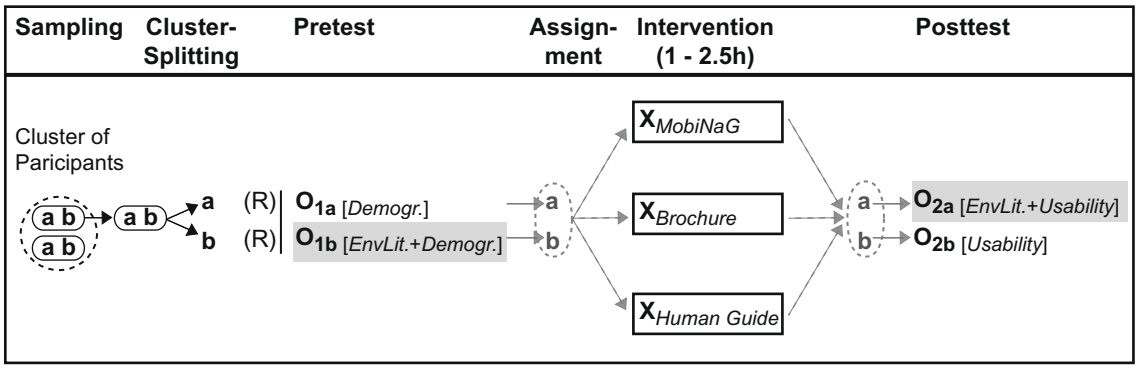

Fig. 3. Quasi-experimental pretest/posttest design with comparison groups, with a and b representing a cluster of two children. The same design was employed for adults and their cluster will later be resembled by A and B.

2.3. Study design and procedure

In order to investigate the differences between computer-based media and traditional interpretive media in facilitating EE interventions including in particular the direct experience of the natural environment the study was set up as a combination of an ethnographic field survey and a field experiment attempting to maintain a high degree of realism with regard to the application domain.

With reference to Bittner (2003), this study has been designed as a quasi-experimental pretest/posttest design with comparison groups as displayed in Fig. 3. Subjects were sampled as clusters in the form of families or school classes. Such a pretest/posttest design is commonly used in the field of EE in order to determine an effect of the intervention (Leeming, Dwyer, Porter, & Cobern, 1993). However, especially in the case of a short-term intervention, with at most 2.5 hours (h) between observations, a practice or learning effect is likely (Greenwald, 1976). To avoid this, the posttest measurement would need to be taken from a different cluster of subjects. However, as Bittner (2003) points out the pretest and posttest groups should be as similar as possible in order to make a valid comparison between the groups. As a solution to this dilemma Bittner (2003) proposes an alteration of the classic pretest/posttest design in the way that a cluster is split into ideal halves, which are then assigned, respectively, to pretest or posttest. A similar approach has been taken in this study (see Fig. 3). Following their arrival at the visitor center and a brief introduction, the families were asked to take a first test before engaging in the EE activity. Prior to the pretest the family cluster was split. Parents were randomly assigned to group A or B and children randomly to group a or b. Thereafter, all subjects were asked to take the pretest based on a semi-standardized self-completion questionnaire. As described above, at this point only half of each sub-cluster (compare Fig. 3 group b) received a questionnaire that included the instrument (i.e. questions addressing environmental literacy variables) next to socio-demographic elements. The other half of the cluster was at the same time administered a questionnaire that only included the socio-demographic elements. This procedure is recommended to provide the impression of equal treatment and avoid unnecessary frustration or bewilderment in either the pre or posttest group (Bittner, 2003). Following the pretest the entire family as a group was randomly assigned to one of the three treatments, a self-guided interpretive tour with the mobile nature guide prototype ($X_{MobiNaG}$) or a self-guided tour with a brochure ($X_{Brochure}$) or a guided interpretive tour administered by a human guide ($X_{HumanGuide}$). All EE interventions had the same content and essentially, differed only in the presentation medium. The families assigned to self-guided media were granted as much time as they needed to complete the tour at their own pace. All groups were accompanied by an experimenter making observations. The intervention lasted for 1–2.5 h. Immediately after the tour, participants were asked to take the posttest. In a kind of "measurement counterbalancing" the other half of the adult and child cluster (compare Fig. 3 group a) was now served with the environmental literacy instrument plus a usability questionnaire. The members of B and b were vice versa asked to complete only the usability questionnaire.

Essentially, the same procedure was performed with the school classes participating in the evaluation. The children enrolled in a class were randomly assigned to group a or b before taking the pretest. Following the pretest, sets of students from both groups were joined and assigned to one of the three treatments. For organizational and pedagogical reasons, sets assigned to a self-guided tour could not exceed three children.

2.4. Instrument

The evaluation of effects of interventions requires a valid instrument (Bogner, 1998a). In this study the impact on the participants environmental literacy was assessed by measuring a number of environmental literacy components including: Knowledge, attitude, values, and concerns as well as behavioral intention/behavior. Corresponding to these components, scales were developed to obtain a pretest and posttest measure of the participants' environmental literacy. Two different versions of the instrument were designed, one for children and one for adults. A total of 21 and 20 items were distributed among the four scales of the children and those of the parents, respectively. In accordance with the recommendation by Leeming et al. (1993), the instrument for this study was not generated entirely from scratch but items from existing instruments were employed.

The knowledge scale was formed from a combination of items evaluating system and action related knowledge adapted from Frick (2003) as well as knowledge items assessing the retention of facts related directly to the content of the intervention. The attitude scale is composed of statements related to the utilization or exploitation of nature, adapted from Bogner, Brengelmann, and Wiseman (2000) as well as Bogner and Wilhelm (1996). Furthermore, items regarding the interest and consideration for conservation were used based on Bogner and Wilhelm (1996) as well as Bittner (2003). The values and concerns scale was built from items concerning the sense of responsibility taken from Kaiser, Wölfing, and Fuhrer (1999), Bogner et al. (2000). In addition statements were included, assessing empathy, in particular perspective taking with respect to other organisms, adapted from studies by Schultz (2000) and the Interpersonal Reactivity Index (IRI) by Davis (1980). Finally the behavior scale includes items expressing verbal commitment by Bogner and Wilhelm (1996) as well as Bittner (2003). Furthermore, statements of reported behavior, based on the "General Ecological Behavior scale" by Frick (2003) and items from the "Actual Behavior scale" from Bogner and Wilhelm (1996), are included. Similar to related studies (Bittner, 2003; Bogner & Wilhelm, 1996; Bogner, 1998b; Bogner et al., 2000; Leeming, Porter, Dwyer, Cobern, & Oliver, 1997), the questions of the attitude, value/concern, and behavior scales were presented in a bipolar 5-point Likert response format, always including an "undecided" category. Items were generally accredited 5–1 points with the most proenvironmental response receiving 5 points and the least proenvironmental 1 point. Four of the items on the children/student questionnaire and five items on the parent questionnaire were negatively connoted and reverse scored in order to reduce the likelihood of response sets (Leeming et al., 1997). Only the knowledge scale items were not presented as rating statements but as questions with a multiple-choice answers similar to Frick (2003).

Other EE outcome evaluations (Bittner, 2003; Unterbruner & Unterbruner, 2005; Dillon et al., 2006) have shown that additional factors including socio-demographic variables have an influence on the environmental literacy components in addition to the treatment. Thus, semi-standardized questions on demography (i.e. pretest) and usability (i.e. posttest) were added to the questionnaires. Next to basic socio-demographic characteristics of the participant (i.e. age, gender, class level, occupation, etc.), the demography section also assessed additional factors that may have an influence on environmental literacy. With reference to studies by Bittner (2003), Brämer (2003), this encompassed variables evaluating the individual state of nature experience, the engagement of family and friends in conservation, and the perceived environmental state of the hometown. Further, questions were included that relate to prior experience with environmental interpretation, the test site, and mobile computing devices.

The usability part of the questionnaire was designed to evaluate the users' overall satisfaction with the EE activity, as well as the perceived quality of guidance and assistance by the respective guide medium. This section was composed of semi-standardized as well as multiple choice questions and rating statements. The respective items were designed with reference to related work discussing principles of successful interpretation (Ham, 1992; Moscardo, 1996; Bittner, 2003).

2.5. Statistical methods

For testing differences between two groups, we applied parametric and nonparametric two-sample tests. Relationships between variables were examined using the general linear model formulation with subsequent ANOVA and ANCOVA analyses. As graphical methods, we used boxplots and interaction plots.

3. Result

3.1. Effects on components of environmental literacy

3.1.1. Children

The analysis of the knowledge scale data shows a significant increase in knowledge following the intervention. This intervention effect (i.e. effect of participating in the tour) has been detected for all groups as no significant differences could be determined between the media groups (see Fig. 4). The influence of socio-demographic variables on environmental literacy measures, assessed during the pretest, was examined using general linear models (see Table 4). The school form that participants attended, their age as well as their degree of alienation from nature had a significant influence on their environmental knowledge. Children enrolled in the advanced track school form achieved significantly higher knowledge scores. Looking at age the results show, that knowledge increases with children's age. In this study alienation from nature has been defined as a sum scale of items relating to prior knowledge on common plants, animals and an understanding for plants as a food source as well as self-reported frequency of direct experience of nature. The results of the analysis show, that children with a lower degree of alienation from nature score higher on the knowledge scale.

The data exhibit a strong interaction between intervention and school form (see Fig. 5). Children attending the advanced track schools started out with higher knowledge scores and also had the smallest increase in knowledge as a result of the intervention. However, as Table 4 shows, this interaction did not turn out to be significant after taking into account the other covariates.

No effect of the intervention on the attitude of the children was determined by the analysis. Only additional factors such as the alienation from nature and the school form had an influence on the children's attitude scores. The mean attitude score was lowest among those children with the highest degree of alienation from nature. Further the attitude scores of children attending the basic school form (S.HS) was significantly lower than those of the ones attending the advance school form (K.GY). Similar results were documented for the values

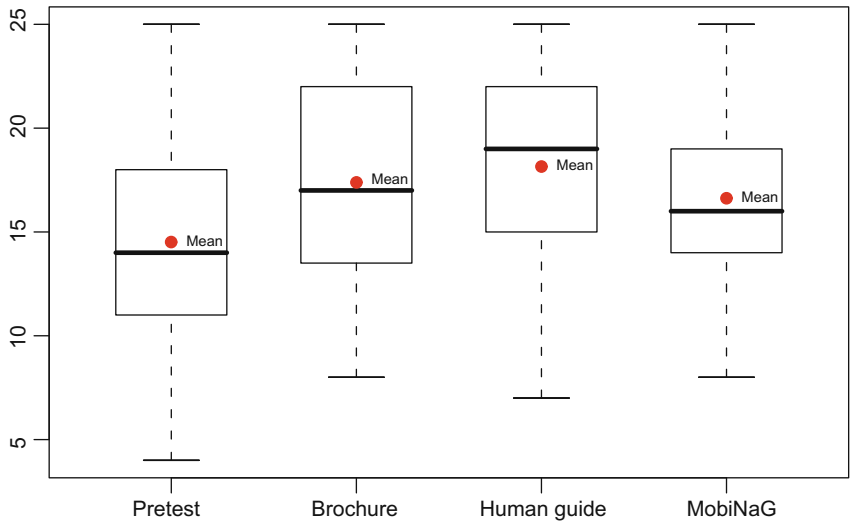

Fig. 4. Boxplot of pre and posttest knowledge scores for the children.

Table 4
ANOVA table of the linear model of knowledge scores

Variable	Type II SS	Df	F statistic	*P* value
Test	443.39	1	27.6961	<0.001
Class2	605.10	3	12.5990	<0.001
Age	185.60	1	11.5936	<0.001
Alienation	132.39	1	8.2694	0.005
Test:class2	80.73	3	1.6810	0.173

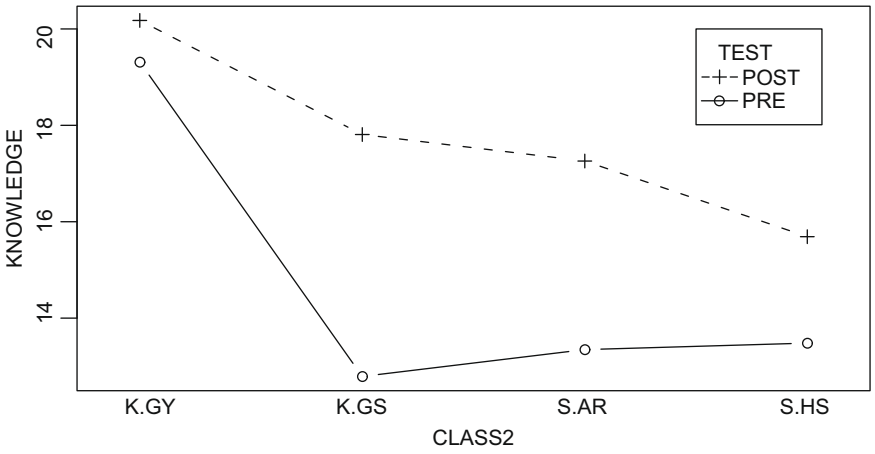

Fig. 5. Interaction plot of pre and posttest knowledge scores depending on school form (K.GS = elementary, K.GY = advanced track, S.AR = medium track and S.HS = basic track).

and concerns scores of the children. No influence of the intervention on the values and concerns of the children was detected. For those children with a higher degree of alienation from nature, the value and concern scores also tended to be lower. Neither the intervention nor the utilization of a specific interpretation medium led to a considerable change in the behavior scores of the children. Still, the behavior scores were also influenced by alienation from nature and school form. The mean behavior scores were significantly lower for those children with a high degree of alienation from nature. In comparison to the children enrolled in an advanced track school, those attending other school forms displayed significantly lower behavior scores. Here, the lowest scores were achieved by the basic track participants.

3.1.2. Adults

Likewise for the adults the participation in the intervention resulted in a significant increase in knowledge scores. As anticipated by looking at Fig. 6, the analysis did not yield a significant difference between media groups (i.e. no media effect). Similar to the results for the children, socio-demographic variables exerted an influence on the environmental literacy components of the adults. One of the crucial additional factors with respect to the knowledge scores of adults was their level of education. The participants with an academic education had significantly higher knowledge scores on the pretest than those with no academic education. On the posttest, however, there is no sig-

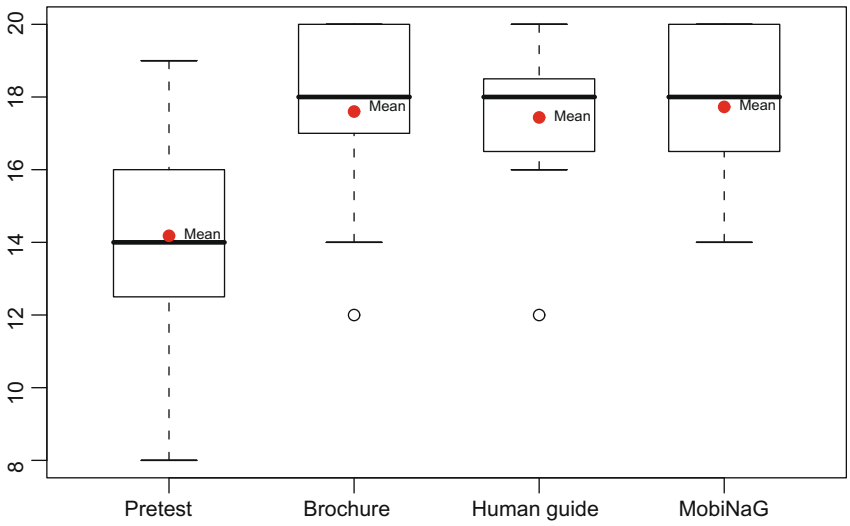

Fig. 6. Boxplot of pre and posttest knowledge scores for the adults.

nificant difference between these two groups, indicating, that the adults with no academic education gained more knowledge from the intervention. Another additional factor that influenced the knowledge scores was the "affinity to nature" variable, representing the self reported frequency of direct experience of nature. Those adults stating daily direct experience of nature generally achieved higher knowledge scores than those reporting regular or rare direct experiences.

With respect to attitude the analysis reveals that the intervention led to a significant increase in attitude scores of the adults. No significant difference was found between the media groups, though. Further, the occupation of the participants tends to influence the attitude scores. Adults that work in the life-science domain had considerable higher attitude ratings than those working in an engineering profession. Neither an intervention nor a media effect was found for the values and concerns scores of the adults. There was also no substantial influence of additional factors on the values and concerns scores. The mean behavior score of the adults has increased significantly following the intervention. Still, there was no effect of the utilization of different interpretation media. Also the behavior scores were influenced by the occupation of the participant. Again, those working in the life-sciences but also craftsmen and service employees had significantly higher behavior scores than engineers.

3.2. User satisfaction

In the posttest, the overall satisfaction of the users with the interpretive presentation by the respective guide medium was evaluated based on the participants' rating of statements relating to their motivation during and immediately after the intervention (e.g. recommending the tour, willingness to participate another time in a similar tour, attentiveness during the tour). Further the participants were asked to rate a number of aspects characterizing how they perceived the efficacy of the tour (e.g. opportunity for direct experience, comprehensibility, convincingness, entertainment). Since the potential distraction by new technologies from direct experience of nature is one of the key concerns of educators, the participants were also asked to specifically rate how much they felt distracted by the intervention. In addition, users were asked to explicitly assign grades to the guide medium and their overall satisfaction with the tour.

3.2.1. Children

The motivational statements were compiled into a motivation sum scale. The analysis of this sum scale for children did not yield a difference between users participating in different media groups. But the results show, that the additional factors assessed during the pretest can also have an influence on the user satisfaction. In case of the motivation sum scale, a moderate but still significant influence of alienation from nature was identified. The children with a higher degree of alienation appeared to be less motivated. A similar outcome was documented for perceived efficacy. There was no media effect on the efficacy ratings but also a small influence of alienation, indicating that children with a lower degree of alienation perceived the intervention as more efficacious. According to the analysis of distraction ratings, there was also no difference between media groups indicating that children did not feel more distracted from experiencing the natural environment due to a specific interpretative medium. A slightly significant influence of school form on the perception of distraction was observed, with basic track students feeling slightly more distracted by the intervention than the advanced track students. In addition, children with a lower degree of alienation from nature also felt less distracted by the intervention. Equally, the analysis of the grades given by the children, specifically for their guide, does not reveal a dependency on the guide medium nor any additional factor. The children were also asked to grade their overall tour experience. Here the analysis does reveal a media effect. The group participating in the intervention with the human guide assigned significantly lower grades then the group using the mobile guide.

3.2.2. Adults

The comparison of the motivational statements of the adult participants did yield a significant difference between media groups. The sum of motivation scores was slightly higher among the adults participating in a tour with the brochure compared to those using the mobile guide. The scores of the adults attending the presentation by the human guide were located between the two other groups (with no significant difference to either one) (see Fig. 7).

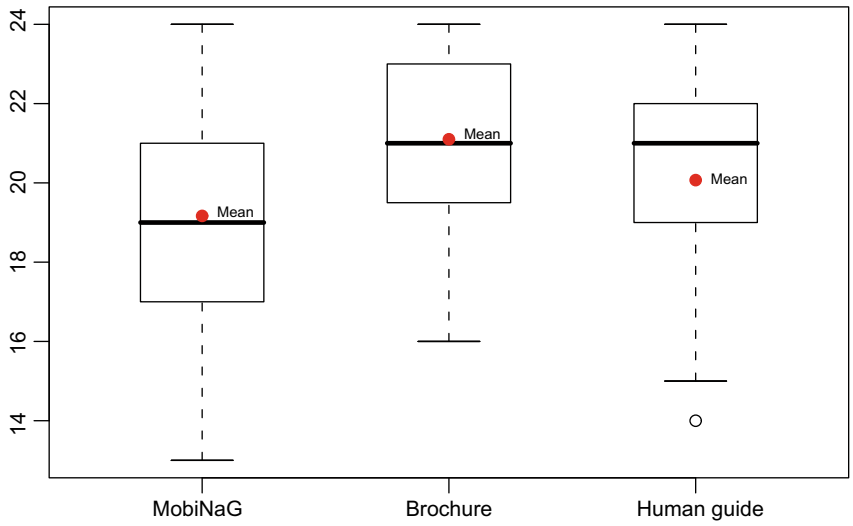

Fig. 7. Boxplot of motivation scores for the adults.

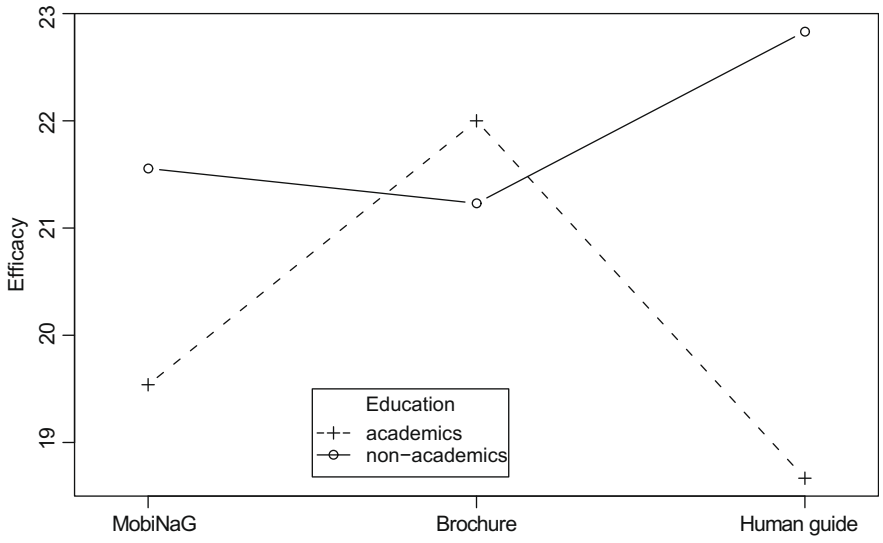

Fig. 8. Interaction plot of efficacy scores depending on education.

The evaluation also included an investigation of how the adults perceived the efficacy of the tour guided by a specific guide medium. The sum scores for the perceived efficacy did not differ significantly between the media groups. But an influence of a demographic factor on the perceived efficacy ratings was detected. The educational level of an adult participant appears to effect the perception of the efficacy of the tour, since those without an academic education rated the efficacy significantly higher. Furthermore, an apparent interaction between educational level and media used during the intervention can be observed (see Fig. 8). Academics attending a tour with the human guide gave considerable lower efficacy ratings than their non-academic peers in the same media group. A similar trend was observed for the adults in the mobile guide group, with the difference between academics and non-academics being less pronounced.

In case of the adult participants some of the individual items forming the perceived efficacy sum scale showed an influence of the media or additional factors and were thus also analyzed individually. This includes the perceived knowledge gain rating. Those adults taking a tour with the human guide, rated their gain in knowledge during the tour significantly higher than those employing the mobile guide. The same trend could be observed for the adult participants employing the brochure. With respect to the interactivity of the intervention, the results show, that the adults taking the tour with the mobile guide, rated the interactivity of the intervention significantly higher than those attending a tour with the human guide. Participants were further asked to judge if, based on the intervention, they now had a better understanding for the necessity to conserve nature. The ratings for this perceived increase in understanding did not differ between media groups but the results did indicate a dependency on the educational level of the participant. Non-academics rated their increase in understanding significantly higher than their academic peers. The analysis of the distraction ratings indicates that adults taking a tour with the human guide or the brochure felt significantly less distracted from the direct experience of nature by the intervention than those utilizing the mobile guide (see Fig. 9).

When asked to assign a grade to the presentation given by the specific guide medium, the human guide received considerably better grades than the mobile guide did from his users. This is different when it comes to the valuation of the games offered during the tour. Here

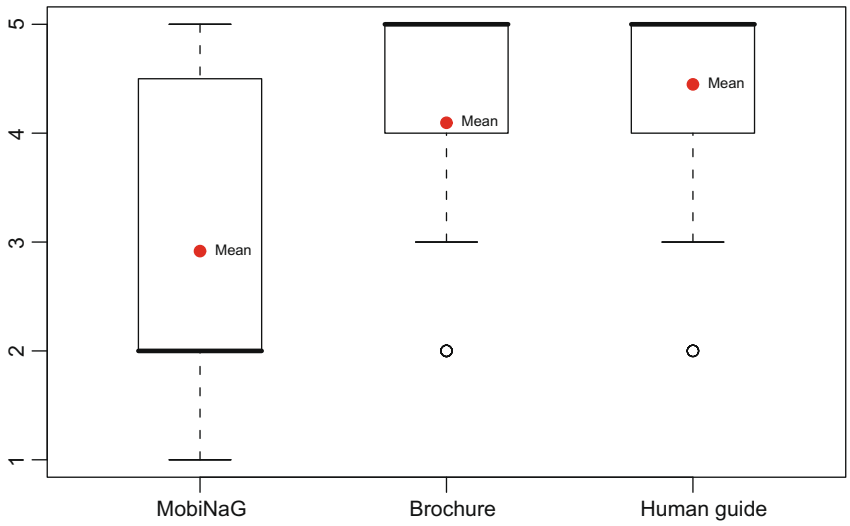

Fig. 9. Boxplot of distraction scores for the adults.

the human guide received significantly lower grades compared to the mobile guide. The analysis of the grades given for the overall impression of the tour experience did not result in any remarkable differences due to the assigned medium or additional factors.

4. Discussion

4.1. Intervention and media effects

The analysis, presented above, reveals a number of intervention effects. Taking part in the environmental interpretation activity resulted in a significant knowledge gain for children as well as adults and also induced significant changes in attitude and behavior scores of the adult participants. With regard to the media effect, which has been a crucial aspect of the study, it is remarkable that none of the measured effects on environmental literacy did depend on the type of interpretive medium employed for the intervention. This lack of a media effect implies that a mobile nature guide system can be successfully employed as an instrument for EE interventions. Despite of its novelty, the mobile learning system appears to have the capacity to induce changes in environmental literacy components, that are comparable to the ones achieved by the long established media, i.e. brochure and human guide.

To date only relatively few studies have evaluated the potential impacts of mobile computers on EE programs. Those who have evaluated the effectiveness of mobile guides in EE interventions, report mostly positive overall effects. In their evaluation of the "Forest Education Support System" Abe et al. (2005) documented that the interest in nature generally increased following a tour with the mobile device. Uzunboylu et al. (2009) found a general increase in the awareness of environmental problems among students who engaged in an EE activity with mobile phones. Several studies report increases in knowledge gain for students attending field-based or informal science courses mediated by a mobile computer (Chen, Kao, & Sheu, 2003; Hennessy, 2000; Lai, Yang, Chen, Ho, & Chan, 2007; Costabile et al., 2008). Still, it should be noted, that these investigations mostly focus on knowledge gains and commonly do not address other crucial environmental literacy components. In addition, only few studies (Chen et al., 2003; Lai et al., 2007) include a similar comparison between a mobile medium and traditional interpretive media. Nonetheless, these studies generally support the finding that mobile computers can be effectively employed in EE and also examinations of the effectiveness of conventional computer use in EE programs indicate, that students in computer-mediated courses performed just as well (Spicer & Stratford, 2001) or even better (Morgil, Arda, Seçken, Yavuz, & Özyalçın, 2004; Aivazidis, Lazaridou, & Hellden, 2006) than those students attending traditional courses. In a study conducted with middle school children engaging in an game to explore a historic site, Costabile et al. (2008) observed that children using a paper-based version of the game performed better than the students using a mobile phone. But they could not identify a significant difference between the learning outcome of the students and thus attribute the difference in performance to the fact that those using the mobile phone were restricted to a sequential order of the game stations, whereas students in the paper-based condition could switch back and forth between different resources more easily.

With respect to the individual components of environmental literacy, the most evident effect of the intervention can be observed for environmental knowledge, since a significant increase in knowledge following the tour has been detected for all school-age children and all adults. This corresponds to the findings of several related studies (Bogner, 1998a; Leeming et al., 1993; Knapp & Barrie, 2001; Daniels & Marion, 2005; Aivazidis et al., 2006; Costabile et al., 2008).

This confirms that the intervention used in this study can adequately serve the purpose of transferring knowledge on the given environment and thus fulfills a core requirement of EE interventions (Knapp & Barrie, 2001). Still, it needs to be taken into consideration that this study did focus on immediate gains in knowledge assessed directly after the intervention. Future research should include follow up measurements to determine the persistence of the measured effects over time, as has been proposed in the outcome research literature (Bittner, 2003; Bogner, 1998a; Leeming et al., 1993).

Attitudes are considered a mediating variable between effectiveness knowledge and behavioral intention (Frick, 2003). Thus, attitudes can be assumed to have a more immediate effect on environmental behavior and Pooley and O'Connor (2000) suggest that environmental educators should in particular try to change attitudes. However, the results of this study show no significant effect of the intervention on

the environmental attitudes of the young children. This corresponds to other findings that could not detect an effect of EE interventions on attitudes (Leeming et al., 1993; Eagles & Demare, 1999). A possible explanation for the lack of attitudinal change is given by Rennie (1994) who points out that attitudes are learned over time. In addition, both Bogner (1998a) as well as Bittner (2003) confirm from studies with school classes, that short term informal EE interventions have only limited potential to induce permanent changes in attitudes. In contrast to the children's scores, however, the attitude of the adults was increased significantly due to the intervention. Since there are also studies in the literature that have detected at least short term changes in attitudes following EE interventions (Leeming et al., 1993; Marynowski & Jacobson, 1999), theses seemingly contradictory findings appear to mirror a controversy over the effects of EE interventions on the attitudes of the participants in the literature. Gotch and Hall (2004) offer a potential explanation for the observed deviation between the attitude scores of children and adults, though. They point out that the attitudes of younger participants are frequently not well developed yet, reducing the reliability of their responses. Overall, this stresses the need for further research on attitude measurements which has also been suggested by Reid (2006). In addition, to meet the challenge of changing especially the attitudes of children through short term EE interventions, it is all the more important to include affective and emotional aspects in order to target emotions and believes which has been suggested by Rennie (1994), Pooley and O'Connor (2000) as a crucial measure to change attitudes.

The underlying determinants of environmental behavior further include values and concerns (Schultz et al., 2005). The participation in the intervention applied for this study did, however, not result in a change of values and concerns neither for children nor for adults. This is the case, despite the fact that all treatments included elements to promote direct experience as well as perspective taking, aspects which have been suggested by Kals, Schumacher, and Montada (1999), Schultz (2000) to further emotional affinity as well as biospheric concern. However, since values and concerns are considered stable across an individual's life (Fransson & Gärling, 1999), they are even more so than attitudes, difficult to influence through short term interventions (Bogner, 1998a). Based on recommendations by Kals et al. (1999), Fransson and Gärling (1999), Gotch and Hall (2004) future interventions should include an explicit discourse on values or moral ethics and should challenge the participants to thoughtfully examine their present belief structures.

The promotion of responsible environmental behavior is considered the ultimate aim of EE interventions (Bogner, 1998a; Leeming et al., 1993). In the present study, however, the intervention did not induce a change in reported behavior of the children. Similar work by Bogner (1998a) only revealed small effects on behavior, while Leeming et al. (1993) document studies that found a more pronounced effect on the behavior of children. In their study of teenagers and their families, engaging in a mobile pervasive game aimed at changing their household energy consumption, Gustafsson and Bång (2008) report at least a short term effect on behavior. Corresponding to the findings for attitude the results for the adults differ from the findings for the children. The behavior scores of the adults do show a significant intervention effect. A possible explanation for this difference between children and adults is provided by Olli, Grendstad, and Wollebaek (2001) who confirm that differences in generational experiences can lead to discrepancies in environmental behavior. Such generational divergence may be given by common differences in childhood nature experience (Wells & Lekies, 2006). Regular childhood participation in "wild" nature experience is considered to be positively associated with environmental behavior in adult life (Wells & Lekies, 2006; Kals et al., 1999). Potentially, the adults engaged in this study may have still experienced ample nature play, while the younger generations may already lack this extensive exposure. This aspect should, however, be subject to further investigations. It is also possible that adults may have been more susceptible to socially desirable responses due to a sense of obligation towards experimenter (Schahn & Bohner, 2002). Children on the other hand, making less rational choices, may have been less prone to this kind of response bias. Their lack of change in behavior scores may equally be related to the short term nature of the intervention. Further, in the presented study, the participants were encouraged to engage in activities to directly experience the natural environment but they were not explicitly trained in skills or specific environmental responsible actions for everyday life as suggested by Fransson and Gärling (1999). This is an aspect that should also be taken into consideration in the future design of similar interventions.

4.2. Additional factors

Apart from the intervention, additional factors can exert an influence on environmental literacy components and should thus also be considered in the analysis (Bittner, 2003; Unterbruner & Unterbruner, 2005; Dillon et al., 2006).

4.2.1. Age

As one of the standard demographic factors, age was expected to have an influence on environmental literacy components. Still, the influence of age was restricted to the environmental knowledge scores of the children. As was expected, the environmental knowledge of the participants did generally increase with age, which matches the observations in the literature, documenting that the longer the education, the higher the knowledge about environmental issues (Kollmuss & Agyeman, 2002; Daniels & Marion, 2005).

4.2.2. Education and occupation

Factors related to the educational and professional background were detected to have an influence on several environmental literacy components of both children and adults. In case of the children this included in particular the school form. To some extend this aspect can be considered a peculiarity of the 3-tier system of secondary education in Germany, where students are assigned to different tracks of the school system based on their performance at the elementary level and to some extend influenced by parental preference (see Dustmann, 2004 for detailed description). Consequently, the "school form" could also be considered an indicator of educational performance.

The knowledge gain of the children was foremost influenced by the school form that they were enrolled in, with the children of the advanced track school form achieving significantly higher knowledge scores. Based on the selection procedure mentioned above, these children can generally be considered to be stronger performers with respect to knowledge retention and presumably also have higher prior knowledge about environmental issues, providing a likely explanation for their higher achievement in knowledge scores. It can be assumed, that another effect is interlinked with this phenomenon. Children attending the advanced track schools are frequently more likely to come from a family were the parents themselves own an advanced educational degree (Dustmann, 2004). In addition, parental education is assumed to assist school success which may contribute to environmental knowledge and access to matters of environmental concern. Hampel, Holdsworth, and Boldero (1996) for instance refer to empirical data, indicating greater environmental concern among adolescents whose parents have had an above average length of education. The interaction that has been detected between intervention and school

form confirms the assumption, that advanced track children have by far the highest environmental knowledge prior to participation in the intervention (see Fig. 5). It is striking though, that in spite of their high level of prior knowledge, the advanced track students also exhibit the smallest increase in knowledge based on the intervention whereas elementary school children show the largest increase in knowledge following the intervention. This again matches findings of Unterbruner and Unterbruner (2005) as well as Daniels and Marion (2005) who attributed this observation to an "easy media effect" implying that students who already know a lot may think that they already know it all and thus are not prepared to acquire new knowledge from the intervention.

In case of the adults, the "level of education" has a similar effect than the "school form". Adults with an academic degree had significantly higher knowledge scores on the pretest but those with vocational training could gain more knowledge from the intervention. Hampel et al. (1996) confirm that those with a higher level of education (interlinked with socio-economic status) tend to have higher environmental knowledge. Further, it can be assumed, that the form of the contents used in the intervention were more suitable for those with vocational training and thus less challenging for academics. This is also confirmed by the result, that those adults with vocational training also rated their perceived increase in understanding of the conservation issue higher due to the intervention. It can thus be assumed that the "easy media effect" described above also applies to the adults.

Education also had an influence on the attitude ratings. It could be observed, that the children enrolled in the basic school form had significantly lower attitude ratings than children in the advanced school form. Those with the highest degree of alienation achieved the lowest attitude scores. Based on the attitude model by Rosenberg and Hovland (1960) environmental attitudes comprise a cognitive, an affective, and a behavioral component. The cognitive component is related to knowledge as well as opinions and a person's beliefs about an object associated with this knowledge (Kaiser et al., 1999). This relationship of attitude to knowledge may account for the influence of the school form and may explain that those children attending advanced level schools entered the evaluation with more environmental knowledge and also achieved higher attitude scores.

In case of the adults it was the occupation of the participants which had an effect on attitudes. Adults working in the life science domain displayed considerably higher attitude ratings than those working in an engineering field. Other research confirms that professional occupation can have an influence on environmental concern and subsequently also attitudes, with adults in the humanities, creative arts, social sciences and biological sciences showing a stronger association between occupation and their environmental concern than those with extended training in the technical, engineering and business spheres (Hampel et al., 1996). As potential explanations for this association, early childhood experiences in nature and its influence on occupational preference (Wells & Lekies, 2006; Chawla, 1998) as well as connections between the occupation and the natural environment (Hampel et al., 1996) are discussed in the literature.

Finally, also behavior was influenced by education. The advanced track school children had the highest scores on behavior and behavioral intent questions. Since the attitude scores of advanced track students were also higher and attitude is considered a direct precedent of behavior (Pooley & O'Connor, 2000), this finding fits into the overall picture.

In case of the adults the behavior scores were influenced by occupation, with the participants in the field of life-science as well as craftsman and service employees displaying higher behavior scores than engineers. A number of studies do support this relationship between occupation/education and environmental behavior (Olli et al., 2001; Chawla, 1998). It can potentially be assumed, that those working in technical disciplines are by large less likely to commit to responsible environmental behavior.

4.2.3. Alienation

Apart from education, alienation from nature was identified as another factor which influenced especially the environmental literacy components of the children. The alienation sum scale was designed to give insight into the children's prior knowledge and in particular their frequency of direct experience of nature. The analysis revealed, that the children with a lower degree of alienation from nature achieve higher environmental knowledge scores. This finding is consistent with the observations in the literature, where next to prior knowledge also frequency of exposure to nature (i.e. personal experience of nature) has a strong influence on environmental literacy (Hampel et al., 1996; Kals et al., 1999; Bittner, 2003). The positive relationship between direct experience of nature, here characterized by affinity, and environmental knowledge also holds true for the adults (Hampel et al., 1996). Since the affective component of attitude is also considered to be positively related to direct experience (Wells & Lekies, 2006), it can be assumed that more frequent exposure to nature should result in a more positive environmental attitude. The results of the children match this assumption since the children with the highest degree of alienation displayed the lowest attitude scores. The children's degree of alienation from nature also affected their environmental values and concerns, which is revealed by the fact that for those children with a higher degree of alienation the values and concern scores tended to be lower. This relationship can be explained by means of the concept of "emotional affinity toward nature" proposed by Kals et al. (1999) who have shown, that the worry about the environment (i.e. environmental concern) strongly depends on direct experience of nature. Since environmental concern is also regarded as an important precondition for the formation of behavioral intention (Schultz et al., 2005), it comes as no surprise, that those children with a higher degree of alienation also achieved lower behavior scores.

The influence of these additional factors (i.e. school form, age, and alienation) suggests that it is of particular importance to deliver EE interventions in form of target group specific presentations. Bittner (2003) for instance suggests that the effectiveness of short term interventions can be improved by tailoring the presentation to age and school form of the participants. In particular for attitude change campaigns Milfont, Duckitt, and Cameron (2006) point out that it is essential to identify the target audience and use different persuasive messages. The adaptation of the presentation to the needs of different target groups is actually considered a key strength of context-aware guide systems (Dias et al., 2004). Due to the design of the experiment, however, the personalization capabilities of the mobile nature guide systems have not been fully employed in this study. Future research should further investigate the effects of more extensive personalization of interventions by a mobile nature guide on the environmental literacy components. In addition, in order to gain more explicit insight into the effects that an intervention may have on the environmental behavior of its participants, subsequent research should attempt to control for the discussed additional factors during sampling.

4.3. Did user satisfaction differ between EE media?

Although, the type of interpretive medium employed for the intervention did not affect the environmental literacy components, the different media still resulted in differences regarding the satisfaction of the participants with the intervention.

The motivation of the children following the participation in the intervention did not differ significantly between the media groups based on the assessed motivational statements. This corresponds to the findings of Costabile et al. (2008) who could not identify a difference in engagement of groups of students (age 10–12 years) participating in an exploration game with either a paper-based guide book or a mobile phone. The analysis conducted for the study presented here did, however, detect a media effect on the motivational statements of the adults, with those that used the brochure scoring higher on the motivation sum scale than those adults using the mobile guide. These results seem to contradict the findings of Lai et al. (2007) which show that the use of mobile computers in EE programs increased the intrinsic motivation of the participants. Lai et al. (2007) found in their study of mobile experiential learning, that children using a PDA during a field trip were more motivated than their counterparts employing a paper-based workbook. A potential reason for the lower motivation ratings in adults may be given by the number of usability issues that were encountered while operating the prototype system (e.g. readability problems due to reflections of sunlight on the display or malfunctions of the GPS receiver unit). Based on their common experience with desktop computers these issues may have induced a fair amount of frustration leading to a detrimental effect on motivation ratings. Nonetheless, these usability issues apparently did not affect the children's motivation, since their motivation scores for the mobile guide did not subside below the scores for the other media. Another aspect which likely contributed to the media effect in adult motivation scales is related to their degree of involvement in the intervention. The accompanying experimenters observed, that the adults participating in a tour with the self-guided media, were frequently more involved in the tour also engaging in the activities themselves. Especially in case of the brochure groups they repeatedly took on the role of a facilitator for the overall tour and its activities. The motivational statements of the children were also affected by the degree of alienation from nature with those children with a higher degree of alienation being less motivated. According to Rennie (1994) the motivation to learn also depends on an affective relationship with a subject. Consequently, the lower motivation of those with a high degree of alienation may again be linked to their lack of direct experience as well as emotional affinity towards nature (Kals et al., 1999).

While the perception of efficacy of the intervention did not differ between the children attending the different media groups, it was again influenced by their degree of alienation. The children with lower degree of alienation perceived the intervention in general as more effective. Likewise for the adults, the perceived efficacy did not differ based on the employed medium. But the perception of efficacy was influenced by the education, since adults with an academic degree generally gave higher ratings for the efficacy of the intervention. These findings tend to confirm the suggestion by Light (1995) that the effectiveness of interpretation, in particular with respect to visitor satisfaction, seems to be the result of an interaction between visitor and interpretive medium, rather than being due solely to the properties of the medium. Thus, not all visitors respond to different interpretive media in the same way but the perceived effectiveness may also depend on prior interest and knowledge of the participant. This may also hold true for the interaction between education and media with respect to perceived efficacy which has been observed in this study. The interaction suggests, that the adults with vocational training, and thus having less prior knowledge, experienced an intervention administered by the human guide as most effective. As has been put forward by Marion and Reid (2007) the human guide with the option for face-to-face communication has the greater capacity to tailor the presentation optimally to the needs of his audience. It may further be related to aspects of credibility of the source (Marion & Reid, 2007) or the desire for personal contact during a learning situation in an unfamiliar environment. The adults with an advance level of education on the other hand experienced the intervention as most effective when using the brochure. This is likely related to their degree of involvement with the particular medium as has been discussed above. Thus, these results again suggest that the interpretive presentation needs to be adapted to the characteristics of the target group in order to improve the satisfaction of the visitor. Furthermore, as has been proclaimed by Marion and Reid (2007), the delivery of a message with multiple methods is better than relying on a single media type. Therefore, to further increase the user satisfaction with the mobile nature guide one option would be to include an interface paradigm, which allows for a more affective interaction with the medium similar to the experience with a human guide, for instance by employing embodied conversational agents (Ruchter, Real, & Düpmeier, 2005).

According to the analysis, the distraction ratings of the children did not differ significantly between the employed media. The only effects on distraction scores of the children were caused by school form and alienation. The observation that basic track students and those with a higher degree of alienation felt slightly more distracted by the intervention can most likely be attributed to the fact, that these are also the groups with less prior knowledge and familiarity with natural environments. It can be assumed that these groups had a shorter attention span and felt overwhelmed by the end of the intervention. Still, it should be stressed, that the children did not feel more distracted by the novel, computer-mediated form of interpretation. This does not coincide with the findings by Rogers et al. (2004) made with students in the "Ambient Woods" project, where a certain amount of distraction was caused by difficulties with operating the devices. Despite the usability issues that were also detected in this study, causing a certain amount of difficulty operating the mobile device also for children, these experiences did apparently not influence their distraction ratings. In two field studies performed with students, during the assessment of an ecological restoration site, it was observed by Rogers et al. (2009) that students can find it distracting to switch between tasks when using a mobile device in situ, if the device and/or the task require intensive concentration. Their findings suggest, though, that having multiple PDAs, such as two devices per group of four to six, enabled fluid interactions and the sharing of information that was not disruptive or distracting, leading to increased sense making activities among the students. Since, in the study presented here, student groups of three usually shared just one PDA, providing an additional device for one group might have further improved their learning experience.

The adults, in contrast, did feel significantly more distracted from experiencing nature when using the mobile nature guide system. This corresponds to the findings of Hsi (2003) who discovered during the evaluation of a mobile guide, used in an hands-on science exhibition, that especially younger users appeared to switch their attention back and forth easily between the handheld device and the exhibit while other adult visitors noted that the mobile system contributed to a sense of isolation from social interaction with others as well as from interaction with the exhibits. With respect to the adult visitors participating in the present study, it can be assumed that they were more intent on recreational and educational aspects and less fascinated by the novel technology. Consequently, they felt more distracted from their experience and more annoyed by usability issues. Whereas the children are likely more accustomed to utilizing computers simultaneously to engaging in other experiences. Furthermore, based on the assumption for this study children can be expected to have been especially focused on the mobile device due to the fascination by the technology. This is supported by the findings of Hennessy (2000) who confirms the enthusiasm of children for mobile computers and also points out that children learned to used handhelds quickly and easily. Thus, even if they were more distracted from exploring nature, they probably did not experience it as isolation. Still, the aspect of distrac-

tion should be given further thought when designing future mobile nature guides. On the one hand improvements in mobile usability, such as a more unobtrusive, minimal attention display may help to further reduce distraction also for adults. This may encompass the usage of audio messages as suggested by Schwabe and Göth (2005) based on a study with university students evaluating a mobile learning game. As has been pointed out above, there are also aspects such as the distribution of the mobile devices (Rogers et al., 2009) as well as the size of teams engaging in an intervention (Schwabe, Göth, & Frohberg, 2005) which should be taken into consideration.

When asked to explicitly grade different aspects of the intervention a certain tendency is revealed that adults do not only feel more distracted by the mobile guide but also tend to favor traditional media in other aspects. For instance, when assigning grades to the presentation by their guide medium, the human guide achieved considerably better results than the mobile guide system. Equally, those adults taking the tour with a human guide personally rated their knowledge gain significantly higher than the attendees of the mobile guide tours. Both findings support the conclusion that adults are less impressed by the application of the new technology and despite the lack of a media effect on environmental literacy, they favor the human guide as an interpreter. As has been pointed out previously, this is probably related to the desire for personal contact (Spicer & Stratford, 2001) as well as the paramount capacity of the human guide for interpersonal communication (Marion & Reid, 2007) and personalization. Potentially, the integration of embodied conversational agents could further improve the acceptance of future mobile nature guides. Nonetheless, the adult participants did appreciate the interactive qualities of the mobile nature guide as a self-determine medium since with respect to games it received significantly higher grades than the human guide.

The grade that the children assigned to their guide medium did neither differ significantly between the media groups nor were they influenced by additional factors. However, a certain response bias towards good and very good grades, due to the children's familiarity with the school grading system, is likely. Still, when asked to judge their overall experience during the intervention the group that engaged in the intervention with the mobile nature guide assigned higher (i.e. better) grades to their overall experience than the children attending a tour with the human guide. This corresponds to some degree to the findings of the study by Costabile et al. (2008), where the children using a mobile device during an exploratory game reported more positive features about the medium than their peers using a paper-based version. The fact that despite the lack of a media effect in most of the evaluated components, the children employing a mobile guide are overall more satisfied with the intervention, may indicate an effect of their fascination for new technologies which has also been proclaimed in the literature (Apel & Wolf, 2005; Hennessy, 2000). Uzunboylu et al. (2009) found in their field study, that the majority of students experienced mobile phones as fun and valuable for learning tools. This motivational influence of new technologies has also been documented for mobile learning instruments based on PDAs (Lai et al., 2007). Next to improving the motivation to participate in EE activities a mobile nature guide further has the potential to facilitate the participation of people with disabilities who are frequently still confronted with certain barriers to self-determined interventions (Dillon et al., 2006). Since a mobile nature guide can offer presentations via multiple modalities it can help to remove some of these barriers.

5. Conclusions

This work demonstrates that novel approaches to computer-mediated education employing mobile devices may offer new opportunities in particular to the field of environmental education. The results of the study show that, even at this early state of development, mobile nature guide systems have the capacity to achieve similar effectiveness as traditional interpretive media with regard to influencing environmental literacy. The analysis of the field experiment further confirms the strong influence of additional socio-demographic factors on the components of environmental literacy, which in case of the children includes in particular the degree of alienation from nature. Since this alienation is expected to further aggravate in increasingly urbanized societies, environmental education institutions could benefit especially from the motivational effect of mobile nature guides, suggested by the finding of this study, to encourage the participation of children in activities involving direct experiences of nature.

In order to take full advantage of the possibilities that mobile nature guides offer, certain limitations that have been identified during this study still need to be overcome. Accordingly, subsequent work should especially focus on improvements of the usability and should address the related topic of distraction. Consequently, by combining personalized and location-based information presentation with self-determined exploration, future mobile nature guides could surmount their motivational functionality to further enhance the environmental learning experience of a wide variety of target groups. This also implies that computer-based environmental learning media could be used to make the direct experience of natural environments also accessible to people with disabilities.

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References

Abe, M., Yoshimura, T., Yasukawa, N., Koba, K., Moriya, K., & Sakai, T. (2005). Development and evaluation of a support system for forest education. *Journal of Forest Research, 10*, 43–50.

Aivazidis, C., Lazaridou, M., & Hellden, G. F. (2006). A comparison between a traditional and an online environmental educational program. *Journal of Environmental Education, 37*(4), 45–54.

Apel, H., & Wolf, G. (2005). *Multimedia in der umweltbildung*. VS Verlag für Sozialw.

Baus, J., Cheverst, K., & Kray, C. (2005). A survey of map-based mobile guides. In: L. Meng, A. Zipf, T. Reichenbacher (Eds.), *Map-based mobile services* (pp. 197–213). Berlin: Springer-Verlag.

Bittner, A. (2003). Außerschulische Umweltbildung in der Evaluation – Wirkungen kurz-zeitpädagogischer Maßnahmen auf Umwelt– und Naturschutzinteressen von Schülerinnen und Schülern der Sekundarstufe I. PhD thesis, Universität Göttingen, Verlag Dr. Kovac.

Bogner, F. X. (1998a). The influence of short-term outdoor ecology education on long-term variables of environmental perspective. *Journal of Environmental Education, 29*(4), 17–29.

Bogner, F. X. (1998b). Environmental perceptions of irish and bavarian pupils: An empirical study. *The Environmentalist, 18*, 27–38.
Bogner, F. X., & Wilhelm, M. G. (1996). Environmental perspectives of pupils: The development of an attitude and behavior scale. *The Environmentalist, 16*, 95–110.
Bogner, F. X., Brengelmann, J. C., & Wiseman, M. (2000). Risk-taking and environmental perception. *The Environmentalist, 20*, 49–62.
Brämer, R. (2003). Zurück zur Natur? Die Wald-und-Wiesen-Therapie. *Psychologie Heute, April*, 22–28.
Chawla, L. (1998). Significant life experiences revisited: A review of research on sources of environmental sensitivity. *Environmental Education Research, 4*(4), 369–382.
Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning, 19*(3), 347–359.
Costabile, M. F., De Angeli, A., Lanzilotti, R., Ardito, C., Buono, P., & Pederson, T. (2008). Explore! possibilities and challenges of mobile learning. In CHI '08: Proceeding of the twenty-sixth annual SIGCHI conference on human factors in computing systems (pp. 145–154). ACM: New York, NY, USA. ISBN 978-1-60558-011-1.
Daniels, M. L., & Marion, J. L. (2005). Communicating leave no trace ethics and practices: Efficacy of two-day trainer courses. *Journal of Park and Recreation Administration, 23*(4), 1–19.
Davis, M. H. (1980). A multidimensional approach to individual differences in empathy. *JSAS Catalog of Selected Documents in Psychology, 10*(85).
Dias, E., Beinat, E., Rhin, C., Haller, R., & Scholten, H. (2004). Adding value and improving processes using location-based services in protected areas. In P. Prastaco, U. Cortés, J.-L. Daz de Len, & M. Murillo (Eds.), *Series research on computing science (e-environment)*. Mexico: Instituto Politécnico Nacional.
Dillon, J., Rickinson, M., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., et al. (2006). The value of outdoor learning: Evidence from research in the UK and elsewhere. *School Science Review, 87*(320), 107–113.
Düpmeier, C., & Ruchter, M. (2004). Mobile guide interface design for exploring the wild. In *Proceedings of 3rd workshop HCI in mobile guides at mobile HCI 04, Glasgow, GB*.
Dustmann, C. (2004). Parental background, secondary school track choice, and wages. *Oxford Economic Papers, 56*, 209–230.
Eagles, P. F. J., & Demare, R. (1999). Factors influencing children's environmental attitudes. *Journal of Environmental Education, 30*(4), 33–37.
Fransson, N., & Gärling, T. (1999). Environmental concern: Conceptual definitions, measurement methods, and research findings. *Journal of Environmental Psychology, 19*, 369–382.
Frick, J. (2003). Umweltbezogenes Wissen: Struktur, Einstellungsrelevanz und Verhaltenswirksamkeit. PhD thesis, Faculty of Philosophy, University of Zürich.
Gotch, C., & Hall, T. (2004). Understanding nature-related behaviors among children through a theory of reasoned action approach. *Environmental Education Research, 10*(2), 157–177.
Greenwald, A. G. (1976). Within-subjects designs: To use or not to use? *Psychological Bulletin, 83*(2), 314–320.
Gustafsson, A., & Bång, M. (2008). Evaluation of a pervasive game for domestic energy engagement among teenagers. In *ACE '08: Proceedings of the 2008 international conference on advances in computer entertainment technology* (pp. 232–239). ACM: New York, NY, USA. ISBN 978-1-60558-393-8.
Ham, S. H. (1992). *Environmental interpretation – A practical guide for people with big ideas and small budgets*. Colorado: Fulcrum Publishing.
Hampel, B., Holdsworth, R., & Boldero, J. (1996). The impact of parental work experience and education on environmental knowledge, concern and behaviour among adolescents. *Environmental Education Research, 2*(3), 287–300.
Hennessy, S. (2000). Graphing investigations using portable (palmtop) technology. *Journal of Computer Assisted Learning, 16*(3), 243–258.
Hsi, S. (2003). A study of user experiences mediated by nomadic web content in a museum. *Journal of Computer Assisted Learning, 19*(3), 308–319.
Kaiser, F. G., Wölfing, S., & Fuhrer, U. (1999). Environmental attitude and ecological behavior. *Journal of Environmental Psychology, 19*, 1–19.
Kals, E., Schumacher, D., & Montada, L. (1999). Emotional affinity toward nature as a motivational basis to protect nature. *Environment and Behavior, 31*(2), 178–202.
Knapp, D., & Barrie, E. (2001). Content evaluation of an environmental science field trip. *Journal of Science Education and Technology, 10*(4), 351–357.
Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3), 239–260.
Lai, C.-H., Yang, J.-C., Chen, F.-C., Ho, C.-W., & Chan, T.-W. (2007). Affordances of mobile technologies for experiential learning: The interplay of technology and pedagogical practices. *Journal of Computer Assisted Learning, 23*(4), 326–337.
Leeming, F. C., Dwyer, W. O., Porter, B. E., & Cobern, M. K. (1993). Outcome research in environmental education: A critical review. *Journal of Environmental Education, 24*(4), 8–21.
Leeming, F. C., Porter, B. E., Dwyer, W. O., Cobern, M. K., & Oliver, D. P. (1997). Effects of participation in class activities on childrens environmental attitudes and knowledge. *Journal of Environmental Education, 28*(2), 33–42.
Light, D. (1995). Visitors' use of interpretive media at heritage sites. *Leisure Studies, 14*(2), 132–149.
Marion, J. L., & Reid, S. E. (2007). Minimising visitor impacts to protected areas: The efficacy of low impact education programmes. *Journal of Sustainable Tourism, 15*(1), 5–27.
Marynowski, S. B., & Jacobson, S. K. (1999). Ecosystem management education for public lands. *Wildlife Society Bulletin, 27*(1), 134–145.
Milfont, T. L., Duckitt, J., & Cameron, L. D. (2006). A cross-cultural study of environmental motive concerns and their implications for proenvironmental behavior. *Environment and Behavior, 38*(6), 745–767.
Morgil, İ., Arda, S., Seçken, N., Yavuz, S., & Özyalçın, Ö. (2004). The influence of computer-assisted education on environmental knowledge and environmental awareness. *Chemistry Education: Research and Practice, 5*(2), 0 99–110.
Moscardo, G. (1996). Mindful visitors – Heritage and tourism. *Annals of Tourism Research, 23*(2), 376–397.
Olli, E., Grendstad, G., & Wollebaek, D. (2001). Correlates of environmental behaviors bringing back social context. *Environment and Behavior, 33*(3), 181–208.
Patalaviciute, V., Düpmeier, C., Freckmann, P., & Ruchter, M. (2005). Using SVG-based maps for mobile guide systems – A case study for the design, adaptation, and usage of svg-based maps for mobile nature guide applications. In *Proceedings of 4th annual conference on scalable vector graphics (SVGOpen 2005), Enschede, The Netherlands*, Sophia-Antipolis Cedex, Fujisawa, Cambridge.
Pooley, J. A., & O'Connor, M. (2000). Environmental education and attitudes: Emotions and beliefs are what is needed. *Environment and Behavior, 32*(5), 711–723.
Ramasundaram, V., Grunwald, S., Mangeot, A., Comerford, N. B., & Bliss, C. M. (2005). Development of an environmental virtual field laboratory. *Computers & Education, 45*(1), 21–34.
Reid, N. (2006). Thoughts on attitude measurement. *Research in Science & Technological Education, 24*(1), 3–27.
Rennie, L. J. (1994). Measuring affective outcomes from a visit to a science education centre. *Research in Science Education, 24*(1), 261–269.
Rogers, Y., Price, S., Fitzpatrick, G., Fleck, R., Harris, E., Smith, H., et al. (2004). Ambient wood: Designing new forms of digital augmentation for learning outdoors. In *Proceedings of interaction design and children (IDC 2004), College Park, MD, USA*. ACM: New York.
Rogers, Y., Connelly, K., Hazlewood, W., & Tedesco, L. (2009). Enhancing learning: A study of how mobile devices can facilitate sensemaking. *Personal and Ubiquitous Computing*, 1–14.
Rosenberg, M. J., & Hovland, C. I. (1960). *Cognitive, affective, and behavioral components of attitudes*. New Haven: Yale University Press.
Ruchter, M., Real, P., & Düpmeier, C. (2005). Comparing a mobile nature guide and a paper guidebook in the field. In *Proceedings of 4th workshop HCI in mobile guides at mobile HCI 05, Salzburg, Austria*.
Schahn, J., & Bohner, G. (2002). Evaluation research in environmental sociology and in environmental psychology: Methodological aspects, Diskussionspapier - Bericht aus dem Psychologischen Institut 85, Universität Heidelberg, Heidelberg.
Schultz, P.-W. (2000). Empathizing with nature: The effects of perspective taking on concern for environmental issues. *Journal of Social Issues, 56*(3), 391–406.
Schultz, P.-W., Gouveia, V. V., Cameron, E., Tankha, G., Schmuck, P., & Franek, M. (2005). Values and their relationship to environmental concern and conservation behavior. *Journal of Cross-Cultural Psychology, 36*(4), 457–475.
Schwabe, G., & Göth, C. (2005). Mobile learning with a mobile game: Design and motivational effects. *Journal of Computer Assisted Learning, 21*(3), 204–216.
Schwabe, G., Göth, C., & Frohberg, D. (2005). Does team size matter in mobile learning? In *ICMB 2005. International Conference on Mobile Business, Sydney Australia* (pp. 227–234). IEEE.
Shultis, J. (2001). Consuming nature: The uneasy relationship between technology outdoor, recreation and protected areas. *The George Wright Forum, 18*(1), 56–66.
Spicer, J. I., & Stratford, J. (2001). Student perceptions of a virtual field trip to replace a real field trip. *Journal of Computer Assisted Learning, 17*(4), 345–354.
Tilden, F. (1957). *Interpreting our heritage*. Chapel Hill: The University of South Carolina Press.
Unterbruner, U., & Unterbruner, G. (2005). Wirkung verarbeitungsfördernder multimedialer Programmgestaltung auf den Lernprozess von 10- bis 12-jährigen. In R. Klee, A. Sandmann, & H. Vogt, (Eds.), *Lehr- und Lernforschung in der Biologiedidaktik*, Innsbruck, Wien, Bozen. Studien Verlag.
Uzunboylu, H., Cavus, N., & Ercag, E. (2009). Using mobile learning to increase environmental awareness. *Computers & Education, 52*(2), 381–389.
Van Velsor, S. W. (2004). A qualitative investigation of the urban minority adolescent experience with wildlife. PhD thesis, University of Missouri.
Wells, N., & Lekies, K. (2006). Nature and the life course: Pathways from childhood nature experiences to adult environmentalism. *Children, Youth and Environments, 16*(1), 1–25.