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Evaluating Environmental Knowledge Dimension Convergence to Assess Educational Programme Effectiveness

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Evaluating Environmental Knowledge Dimension Convergence to Assess Educational Programme Effectiveness

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One aim of environmental education is fostering sustainable environmental action. Some environmental behaviour models suggest that this can be accomplished in part by improving people's knowledge. Recent studies have identified a distinct, psychometrically supported environmental knowledge structure consisting of system, action-related and effectiveness knowledge. Besides system knowledge, which is most often the focus of such studies, incorporating the other knowledge dimensions into these dimensions was suggested to enhance effectiveness. Our study is among the first to implement these dimensions together in an educational campaign and to use these dimensions to evaluate the effectiveness of a programme on water issues. We designed a four-day environmental education programme on water issues for students at an educational field centre. We applied a newly developed multiple-choice instrument using a pre-, post-, retention test design. The knowledge scales were calibrated with the Rasch model. In addition to the commonly assessed individual change in knowledge level, we also measured the change in knowledge convergence, the extent to which the knowledge dimensions merge as a person's environmental knowledge increases, as an innovative indicator of educational success. Following programme participation, students significantly improved in terms of amount learned in each knowledge dimension and in terms of integration of the knowledge dimensions. The effectiveness knowledge shows the least gain, persistence and convergence, which we explain by considering the dependence of the knowledge dimensions on each other. Finally, we discuss emerging challenges for educational researchers and practical implications for environmental educators.

Keywords: *Environmental education; System knowledge; Action-related knowledge; Effectiveness knowledge; Programme evaluation; Knowledge convergence*

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Introduction

The Tbilisi Declaration (UNESCO/UNEP, 1978), as one major document guiding environmental education, states five goals for educational programmes: awareness, knowledge, attitudes, skills and participation. The aim of enhancing these determinants is to foster sustainable action at the individual level, thereby reducing people's harmful impact on the environment. Besides improving motivational determinants like attitudes towards the environment or addressing moral conservation norms, improving environmental knowledge is one element of promoting conservation behaviour (Bamberg & Möser, 2007; Hart, 2002; Heimlich & Ardoin, 2008; Kaiser, Roczen, & Bogner, 2008).

In this article, we focus on environmental knowledge as one relevant factor that affects conservation behaviour. Environmental knowledge can assist individuals to effectively and successfully cope with real-life everyday environmental challenges through appropriate environmental action (Frick, Kaiser, & Wilson, 2004). Conscious environmental action requires not only that an individual possesses a high overall environmental knowledge level, but also a profound knowledge integration as well in terms of merging the various knowledge dimensions, which is known as knowledge convergence. This knowledge convergence tends to increase with the environmental knowledge level and plays an important role in encouraging appropriate action towards environmental preservation and/or conservation (Axelrod & Lehman, 1993; Frick et al., 2004).

Yet, the younger generation's factual environmental knowledge is often reported as being 'lower than might be hoped' (review by Rickinson, 2001, p. 227). This is not surprising, as even adults are uninformed or misinformed with regard to general environmental issues, for instance, about the causes of air and water pollution and the potential solutions for these problems (Coyle, 2005). A follow-up study in 2013 to Coyle's report on the Environmental Literacy in America (2005) found that only 16% of the population, mostly young and well-educated, 'is knowledgeable about the environment'. A total of 46% are open to learning and understanding and are willing to adopt conservation behaviour (NEEF, 2013, p. 11). Further, a study by Gunckel, Covitt, Salinas, and Anderson (2012) on student accounts of water in socio-ecological systems revealed that students had an average explanation level (a level between 2 and 3), and that students' learning needs to be supported by education to reach the highest level of reasoning (level 4: literate citizens). In conclusion, the low to average level of public knowledge can and should be enhanced, for example, by appropriately designed environmental education.

Environmental Knowledge

The acquisition of factual knowledge is regarded as the classic objective of formal education (Kaiser et al., 2008). However, for coping with complex environmental issues, factual environmental knowledge alone is not sufficient to address real-life challenges. Frick et al. (2004) hypothesise three specific dimensions of environmental knowledge that are ultimately relevant for conservation behaviour: first, a person who understands the natural processes within ecosystems and the effect of human–nature interactions (system knowledge) is more likely to undertake pro-environmental behaviour. Second, one must know what actions can be taken to address environmental problems (action-related knowledge). And third, knowing about the trade-offs and how effective one option/action versus another may be is necessary when choosing from possible options (effectiveness knowledge). In their study, Frick et al. (2004) psychometrically supported this distinct environmental knowledge structure which consists of system, action-related and effectiveness knowledge.

The questionnaire used in our present study consists of questions on the topic of water that reflect each of the three dimensions (system knowledge, action-related knowledge and effectiveness knowledge). In the following, we discuss the three environmental knowledge dimensions and provide examples of the corresponding questions from the questionnaire.

System knowledge describes basic scientific knowledge (Frick et al., 2004), such as knowledge about the relationships of ecosystems, the interaction of organisms and reasons for environmental problems (Kaiser et al., 2008). One example taken from our multiple-choice instrument on system knowledge is 'Which of the following countries have the least fresh water?', which ascertains the students' knowledge of the water distribution on the planet, a systematic issue.

Action-related knowledge refers to the knowledge of potential behavioural options which might lead to a specific conservation goal. This specific knowledge dimension can also cover a range of behavioural alternatives, including the knowledge needed to carry them out correctly (Kaiser & Fuhrer, 2003). Our action-related knowledge scale contains the corresponding multiple-choice question 'Which method is effective for saving water?'

Effectiveness knowledge is relevant for choosing behavioural alternatives (Kaiser et al., 2008) because it involves understanding the relative effectiveness of different behaviours and their potential for protecting the environment (Kaiser & Fuhrer, 2003). A corresponding question from our questionnaire is 'How much water can be saved when you shower instead of bathe?' According to Kaiser et al. (2008), effectiveness knowledge is the environmental knowledge dimension which is most often missing in environmental education.

Environmental Education

In many theories and models, environmental knowledge is an important factor which can have a significant influence on conservation behaviour (the review by Heimlich & Ardoin, 2008; Roczen, Kaiser, Bogner, & Wilson, 2014). Therefore, successfully promoting environmental knowledge may influence future conservation behaviour, and this enhancement of knowledge can be accomplished through environmental education. Reviewing several outdoor field courses, Rickinson (2001) mentions Bogner's (1998) study as the most conclusive evidence at that time of environmental education's effectiveness in increasing students' (non-differentiated) environmental knowledge levels: a five-day residential outdoor ecology programme with secondary-school students showed positive changes in environmental knowledge based on a pre-test before the programme started and post-test 4 weeks after the students participated in the programme. There are also examples from more recent studies, which show educational success in the form of knowledge increase in the short term, immediately after participation in a programme, and in the medium term, 3 months later (Fančovičová & Prokop, 2011; Randler, Ilg, & Kern, 2005; Sellmann & Bogner, 2013) or even in the long-term, 6–12 months later (e.g. Bogner, 1998; Farmer, Knapp, & Benton, 2007).

All the above-mentioned studies have demonstrated gains in non-differentiated knowledge related to the environment. According to Frick et al. (2004), however, environmental knowledge is comprised of system, action-related and effectiveness knowledge. To date, the incorporation of the knowledge dimensions into a real-life setting has not yet been researched. To measure all three dimensions in the context of a practical background, we had to develop a new educational unit which deliberately incorporates all three knowledge dimensions. We chose the situated learning theory as the theoretical framework for our study (Lave & Wegner, 1991). In this framework, learners are seen in the social context in which they act and interact. Authentic situations with realistic problems are used to allow students to learn how to solve real-life situations and how to transfer knowledge into different contexts. Social interaction, such as occurs in group work, seems to be a suitable means for enhancing the environmental knowledge corresponding to each of the individual knowledge dimensions, allowing students to articulate the knowledge gained and reflect upon it. Appropriate pedagogical approaches, like learning at workstations (e.g. Sturm & Bogner, 2008) or collaborative group discussions (e.g. Mason & Santi, 1998) may be effective in incorporating the three knowledge dimensions into a single programme. Our review of the literature shows that no programme based on system, action-related and effectiveness knowledge has yet been investigated. We therefore designed a programme that includes suitable didactic methods to foster the three dimensions.

Effective Education in Terms of Environmental Knowledge Gained

Based on the three environmental knowledge dimensions, the term effective education in our study is described and measured in terms of increase in knowledge and the persistence of knowledge. Students who know more after participating in an educational programme can also answer more difficult questions and keep this knowledge over a longer period of time. The programmes described above and many other programmes are only concerned with increasing the amount of students' knowledge, changing from a low to a higher knowledge level. Knowledge convergence in the sense of Kaiser and Fuhrer (2002), different forms of knowledge working together in a convergent manner to foster ecological knowledge, however, has not yet been examined: distinguishing between system, action-related and effectiveness knowledge allows the extent of the merging of the dimensions to be measured. After students' participation in an educational programme, the students' test results should show a tighter correspondence of the individual environmental knowledge dimensions as proof of educational success.

Research Goals

The primary aim of this study is to empirically test and to implement the three knowledge dimensions in an environmental education setting and to evaluate the outcome of a student's participation in the programme (in terms of short-term increase and the persistence of knowledge). In addition to the commonly reported change in knowledge level as a result of programme participation, we want to present and include another indicator for educational success: knowledge convergence, which describes the extent of the learners' integration of the three knowledge dimensions into their knowledge base, which, according to Kaiser and Fuhrer (2002), should better equip students to take appropriate ecological action compared to a knowledge increase in only one or two dimensions. To assure the validity of our results, we assess the homogeneity and reliability of our scales. We used the Rasch model for this scale calibration, as it permits comparison with future studies that are also based on the three environmental knowledge dimensions.

Methods

Participants

Our sample consisted of 228 German (Bavarian) students from primary and secondary general-education schools (fourth and sixth grades): 190 participated in our programme and 38 served as a control group. The mean age of the students participating in the programme was 10.4 years (SD = 1.1), 46.6% were girls and 53.4% were boys. One fourth-grade class and one sixth-grade class were assigned as a control group to exclude any learning effects that might simply result from the repeated completion of our questionnaires. The mean age of the control group was 11.0 years (SD = ±1.23 with 50% girls and 50% boys). Parental consent was required for data to be collected. Since our programme followed the official Bavarian curriculum (Appendix 2), teachers were asked not to teach anything related to the programme topic in school until the retention test had been administered.

Environmental Education Programme

In total, the modules of our residential programme *Water in Life—Life in Water* amounted to approximately 24 hours of guidance spread over four consecutive days (Appendix 1). A short module description together with the corresponding parts of the Bavarian curriculum is provided in Appendix 2. To minimise the teacher variable, one single programme instructor was selected to guide the classes. The programme covered various cognitive and affective aspects taught during indoor and outdoor sessions (for results on the affective aspects please refer to: Liefländer, Fröhlich, Bogner,

& Schultz, 2013). Within the theoretical framework of situated learning (Lave & Wenger, 1991), we implemented various student-centred didactical methods. Group work with social interaction formed the basis of the programme, and most modules contained active hands-on activities. One instructional method we applied was *learning at workstations* (e.g. Gerstner & Bogner, 2010; Sturm & Bogner, 2008; Appendix 2), a cooperative learning approach that enhances social, practical and professional competences as well as supports cognitive achievement (Lord, 2001). One long-term task which we introduced at the start of the week addressed personal water usage and was conducted with the *jigsaw method* (Aronson, 1978). Overall, the design of our programme aimed at equally enhancing system, action-related and effectiveness knowledge.

Procedure

Our test design included a paper-and-pencil pre-, post- and retention test. The pre-test questionnaire was completed at school 2 weeks before the students' participation in the project. At the end of the programme, the post-test was immediately completed at the educational field centre. The retention test (the follow-up test) was administered at school 4–6 weeks later. Demographic data, such as sex and the year and month of birth, were included, together with a strictly confidential code to match the three tests of each student. Our knowledge instrument contained 21 items which were embedded into a larger questionnaire containing 26 additional items (e.g. to determine changes in environmental attitudes and connectedness to nature: for results, see Liefländer & Bogner, 2014; Liefländer et al., 2012). The knowledge items were randomly distributed, differing in their order of appearance at each test time, with the questionnaire taking about 15 minutes for students to complete.

Knowledge Scales

Our new, country-specific programme and instrument quantifies the three environmental knowledge dimensions: system knowledge, action-related knowledge and effectiveness knowledge. The initial ideas for our knowledge instruments were based on the work of Kaiser, Roczen & Bogner (2008), who developed an instrument for adolescents that includes environmental knowledge scales that are not programme-specific. For our own instrument, we first selected a set of questions for each of the three knowledge dimensions which are suitable for our age group and for determining the increase in knowledge. In a second step, nonparticipating same-age students were asked to formulate plausible answers to serve as alternatives for our multiple-choice questions. A teacher expert group assisted with the selection of the three most plausible, but incorrect answers. With one correct and three incorrect statements, the chance of randomly guessing the correct answer for any particular item was 25%. In a third step, all items were pilot-tested with another group of same-age students to assure that the item difficulties were equally distributed and that all the incorrect answers were chosen by at least 8% of all students. An objectivity test was conducted to ensure that the items correspond to the supposed dimensions. For this objectivity test, we gave the questions to several colleagues from the field and asked them to assign the questions to the corresponding knowledge dimension. Only those questions which were assigned to the same dimension by all the experts were chosen as final items for our instrument.

The item responses for each student were coded with 1 for a correct answer and 0 for an incorrect answer. For our analysis, we used the software programme *Quest*, standard version (Adams & Khoo, 1993). The scales were calibrated using the simple Rasch model for dichotomous items (SRM; Rasch, 1980). The Rasch model is a probabilistic model which describes the probability for a correct answer as a function of item difficulty and person ability. For an in-depth description of the model and its formula, please refer to Bond and Fox (2007).

As input variables for the calculations of the knowledge level and knowledge convergence, we used the Rasch person scores expressed in logits. Logits stand for the natural logarithm of the ratio of correct to incorrect answers. The more positive the logit, the more the ratio is shifted towards the ‘correct answer’ and vice versa.

Results

First, we present the results of the Rasch analyses to demonstrate the quality of our instrument. Second, we apply parametric tests to examine the effects our environmental education programme on the increase of overall and specific environmental knowledge. Finally, we determine the extent of knowledge convergence.

Quality of the Instrument

We first calibrated our three environmental knowledge scales according to the simple dichotomous Rasch model to obtain the scales’ descriptive, reliability and fit statistics (Table 1).

The person reliability index indicates the probability of receiving the same person order if a parallel set of items measuring the same construct were applied. For our instrument, we find acceptable person reliability for system and action-related knowledge, but only moderate person reliability for effectiveness knowledge (see Table 1: *Scale descriptive, Reliability*). Besides the moderate reliability, the variance of the effectiveness knowledge scale is lower than the variance of the other scales, which may cause the low reliability. The scale means for person scores range between $M = 0.31$ for system knowledge and $M = -0.22$ for effectiveness knowledge, with action-related knowledge close to system knowledge, $M = 0.23$. The narrow distribution in the effectiveness dimension points to an overall lower effectiveness knowledge level of the participating students. The item reliability index indicates the probability of obtaining the same item order for the item difficulty if this scale were applied to another sample of the same size. Our environmental knowledge scales show high item reliability, ranging from 0.95 to 0.98 (Wright & Masters, 1982).

Table 1. Scale descriptors for person abilities and item and person fit statistics for the environmental knowledge scales

	System knowledge	Action-related knowledge	Effectiveness knowledge
Scale descriptive			
Reliability	0.74	0.72	0.57
% missing answers	1.29	1.73	0.86
M	0.31	0.23	−0.22
SD	1.05	1.01	0.74
Fit statistics			
Item fit			
M(MS)	1.00	1.00	1.00
SD(MS)	0.14	0.11	0.06
Maximum(MS)	1.31	1.25	1.13
Minimum(MS)	0.85	0.83	0.90
$M(t)$	−0.11	0.07	−0.05
SD(t)	1.85	1.64	1.10
Person fit			
M(MS)	0.99	1.00	1.00
SD(MS)	0.24	0.21	0.14
$M(t)$	−0.01	0.02	0.01
SD(t)	1.12	0.97	0.86
Persons with poor fit ($t \geq 1.96$)	3.95%	3.07%	1.75%

Note: A simple dichotomous Rasch model (Rasch, 1980). Seven items are not sufficient for a Rasch analysis, therefore we used all test-time results to obtain a N_{Items} of 21; $N_{\text{Persons}} = 228$. We used the software programme *Quest*, standard version (Adams & Khoo, 1993). Abbreviations found in the fit statistics: Mean (M) and standard deviation (SD) of the weighted infit in their mean square and standardised (t) forms.

The fit statistics for item and person mean squares (MS) are listed in Table 1. The data match the model, as the expected value of the mean squares [M(MS)] for items and persons is about 1.00. No reference point for the standard deviation of the mean squares [SD(MS)] can be given. The MS fit statistic provides evidence for the relative difference in the variations between the observed item/person values and the values predicted by the model. Mean MS values greater than 1.00 represent an underfit, and values below 1.00 represent an overfit (see Bond & Fox, 2007). For items, a MS value of 1.30 indicates a variance within the data for the single item which is 30% higher than predicted by the model. Bond and Fox (2007) consider a range between 0.75 and 1.30 for the MS of items to be an acceptable fit for ordinary multiple-choice tests. All items but one fall into this range of acceptable fit. The one item has an MS of 1.31 and shows an underfit only in the pre-test. In the post- and retention tests, it shows a good fit (MS = 1.08, 1.05), and we therefore choose to keep the item for analysis.

The fit statistics of t-values are valuable for data interpretation, since they are not influenced by the sample size. The used standardised infit t-values of items and persons should have a mean $[M(t)]$ of 0.00 and a standard deviation of about 1.00. The number of students whose results cannot be precisely predicted by the model ($t \geq 1.96$) should be less than 5% of the whole sample. Our sample has less than 4% of participants with a poor fit for each scale (Table 1).

Knowledge Increase and Persistence

Educational success can be described in terms of student obtaining a higher knowledge level after an educational intervention. The results on the knowledge increase and persistence of the three dimensions are presented in Table 2. The corresponding statistical analyses are described in the text.

Through participating in our educational programme, students increased their environmental knowledge in all dimensions. A mixed-design ANOVA reveals a significant interaction between the pre- and post-test, all knowledge dimensions and all groups, $F(2, 452) = 51.69$, $p < .001$. The intervention group differs from the control group and shows a significant overall knowledge increase from pre- to post-test directly after programme participation, $t = 27.16$, $df = 569$, $p < .001$ and $r = .75$ (paired t-test; mean ± SD: -0.75 ± 1.15 and 0.88 ± 1.26, respectively). The environmental education programme therefore had a very large effect[1] on the overall knowledge gain of the participants. The nonparticipating control group, as expected, shows no significant knowledge increase, $t = 0.312$, $df = 113$, $p = .756$ (mean ± SD: -0.59 ± 1.00 in the pre-test and -0.55 ± 0.99 in the post-test).

Table 2. Environmental knowledge level as a function of the environmental education programme

		Experimental groups	
Knowledge	Test time	Control, $n = 38$	Intervention, $n = 190$
System	Pre-test	-0.45 ± 0.86	-0.74 ± 1.18
	Post-test	-0.47 ± 0.93	1.19 ± 1.25
	Retention test	-0.60 ± 1.04	1.02 ± 1.35
Action-related	Pre-test	-0.67 ± 0.88	-0.74 ± 1.19
	Post-test	-0.60 ± 1.32	1.11 ± 1.28
	Retention test	-0.47 ± 1.25	0.91 ± 1.24
Effectiveness	Pre-test	-0.81 ± 1.08	-0.78 ± 1.06
	Post-test	-0.60 ± 0.96	0.33 ± 1.06
	Retention test	-0.81 ± 0.83	0.04 ± 0.99

Note: Mean ± SD of person scores in logits.

Students attending our programme also gained knowledge in each specific knowledge dimension between the pre- and post-tests. The gain in system knowledge is the greatest ($t = 18.75$, $df = 189$, $p < .001$, $r = .81$), closely followed by action-related knowledge ($t = 16.78$, $df = 189$, $p < .001$, $r = .77$). The effect on effectiveness knowledge, however, is smaller ($t = 12.71$, $df = 189$, $p < .001$, $r = .66$). The means are given in Table 2. As expected, the students in the external control group did not gain knowledge in any knowledge dimensions, since they were not provided any instruction regarding the topic of the programme (Table 2).

The increase in the students' overall knowledge, which we have described above, persisted over a 4-week time span. From the post-test to the retention test, the knowledge level does not decrease significantly across the test times, knowledge dimensions and groups, $F(2, 452) = 1.51$, $p = 0.222$. As expected, we find no changes in the control group. The intervention group, however, shows a significant but small decrease in knowledge, $t = 4.79$, $df = 569$, $p < .001$, $r = .20$ (mean ± SD: 0.87 ± 1.26 in the pre-test and 0.66 ± 1.28 in the post-test). Compared to the overall knowledge increase with a very large effect size from the pre-test to the post-test, the decrease corresponds to only a small effect size. The control group neither lost nor gained knowledge between the post-test and retention test, $t = 0.81$, $df = 113$, $p = .418$ (mean ± SD: -0.55 ± 0.99 and -0.67 ± 1.08, respectively).

The knowledge decrease is small for all the specific knowledge dimensions. The system knowledge shows the least decrease ($t = 2.11$, $df = 189$, $p = .036$, $r = .15$), closely followed by action-related knowledge ($t = 2.47$, $df = 189$, $p = .014$, $r = .18$) and effectiveness knowledge shows the greatest decrease ($t = 3.71$, $df = 189$, $p < .001$, $r = .26$).

Knowledge Convergence

In the current study, knowledge convergence describes cognitive achievement in terms of merging of the three knowledge dimensions. A stronger merging of measured knowledge indicates the programme's educational success. We therefore examined the knowledge convergence by correlating each scale with another. A stronger convergence becomes visible if correlations increase over the test times.

The correlations of system knowledge with action-related knowledge and with effectiveness knowledge tend to increase from the pre-test to the post-test and to the retention test (Table 3). The correlation between action-related knowledge and effectiveness knowledge also tends to increase; however, it decreases again from the post- to the retention test. Comparing the correlation coefficient of the independent test times according to Cohen, Cohen, West, and Aiken (2003) revealed only one significant increase in correlations over time: the pre-test and retention test coefficients of the correlation between system knowledge and action-related knowledge revealed $Z = -2.34$, $p = .019$.

Table 3. Change in the convergence of the environmental knowledge dimensions due to students' programme participation

Test time	System knowledge	Action-related knowledge	Effectiveness knowledge
Pre-test			
System knowledge	*0.74*	0.43	0.33
Action-related knowledge	0.31***	*0.72*	0.36
Effectiveness knowledge	0.21**	0.23**	*0.57*
Post-test			
System knowledge	*0.74*	0.60	0.50
Action-related knowledge	0.44***	*0.72*	0.40
Effectiveness knowledge	0.33***	0.26***	*0.57*
Retention test			
System knowledge	*0.74*	0.69	0.56
Action-related knowledge	0.51***	*0.72*	0.28
Effectiveness knowledge	0.36***	0.18*	*0.57*

Note: Diagonal (italics): scale reliabilities; below the diagonal: uncorrected Pearson correlations r and above the diagonal: Pearson correlations r corrected for measurement error attenuation. The correction adjusts the correlation for the unreliabilities of the two measures involved ($r/\sqrt{(\text{reliability}_{\text{scale 1}} \times \text{reliability}_{\text{scale 2}})}$; Charles, 2005). Widely accepted significance tests are available only for uncorrected correlations.

$^{*}p < .05$.

$^{**}p < .01$.

$^{***}p < .001$.

Discussion

Our newly developed and project-specific environmental knowledge scales are of good psychometric quality and demonstrate the effectiveness of our environmental education programme in enhancing knowledge: the students in our educational programme showed a persistent gain in environmental knowledge in all three knowledge dimensions. We also found a tendency of the three knowledge dimensions to overlap as the dimensions become increasingly interconnected.

Evaluation of the Environmental Knowledge Scales

Our scale calibrations revealed the environmental knowledge scales to be reliable and homogeneous according to the Rasch model. According to the item fit statistic, the seven items differ only in their difficulty, but they all represent the attributed latent knowledge dimension. All three knowledge dimensions are one-dimensional and distinct from each other, which is shown by the moderate correlations in the pre-test (see Table 3). However, the effectiveness knowledge scale suffered from a more restricted variance and a lower average mean compared to the other scales (Table 1). Apparently, effectiveness knowledge items were more difficult; in other words, students had a more pronounced lack of knowledge in the dimension of effectiveness knowledge compared to the other dimensions. This is not surprising, since effectiveness knowledge seems to be dependent on the two other dimensions. For example, to be able to answer a question on the most effective water saving technique, one has to know the effectiveness of many different techniques (action-related knowledge). These findings are in line with the findings of Frick et al. (2004), who found effectiveness knowledge to be slightly lacking in a representative Swiss sample, with only 52.9% correct answers, compared to 54.4% correct answers for the system knowledge and 55.4% correct answers for the action-related knowledge in the sample ($N =$ 5000; 18–80 years of age). Nevertheless, we cannot completely exclude the hypothesis that the apparent lack of effectiveness knowledge might be a measurement artefact.

Success of the Environmental Education Programme

Successful instruction involves cognitive achievement, demonstrated by an increase in students' knowledge level (Kaiser et al., 2008). We have selected the system knowledge results to graphically represent and discuss our findings on the knowledge level (Figure 1). For the other dimensions, action-related knowledge and effectiveness knowledge, the graphics were similar.

We found an overall knowledge level increase, which has also been found in previous studies about non-differentiated environmental knowledge (e.g. Fančovičová & Prokop, 2011; Sellmann & Bogner, 2013). Additionally, we show an increase in each knowledge dimension, with the strongest increase for system knowledge,

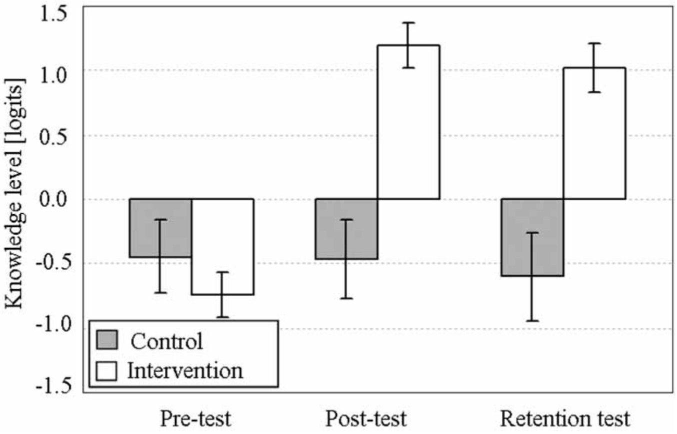

Figure 1. Effect of the environmental education intervention on students' system knowledge level. Error bars represent 95% confidence intervals; CI pre-test [−0.62, 0.03], CI post-test [1.30, 2.00] and CI retention test [1.17, 2.08]

followed by action-related knowledge and then by effectiveness knowledge. This trend of decreasing knowledge gain with respect to knowledge dimension type is striking as well as unexpected, because we tried to equally foster all three dimensions in our programme design. The knowledge dimensions are mutually dependent, and the 'Competence Model for Environmental Education' of Kaiser et al. (2008) describes this interdependence: system knowledge includes recognising the need to act, itself a precondition for gathering action-related knowledge. System knowledge also includes the comprehension of problems, which is a precondition for effectiveness knowledge. A high level of action-related knowledge includes knowledge about many alternative actions and is therefore a precondition for effectiveness (Frick et al., 2004). The knowledge dimensions, so to speak, build upon each other and are dependent on one another. The effectiveness knowledge dimension depends strongly on the other dimensions, and the system knowledge dimension forms the basis for the other knowledge dimensions. Therefore, we assume that for achieving a knowledge increase in the effectiveness knowledge dimension, the other two dimensions have to be regarded as prerequisites.

The students benefited from our educational programme, but we found no complete knowledge persistence. Instead, we found a common knowledge decrease 4 weeks after the end of the programme (see Figure 1 for an example). For the most part, the findings correspond to the majority of cases found in the literature and show the normal trend of knowledge increase and recurrent decrease after a certain time span (e.g. Randler et al., 2005). The decrease was the smallest for system knowledge and the greatest for effectiveness knowledge. With respect to the connection of the three knowledge dimensions discussed above, the stronger decrease in effectiveness knowledge 4 weeks later is not surprising. If action-related knowledge is lacking, a person can no longer use action-related knowledge to determine the relative effectiveness of different actions (Frick et al., 2004). A decrease in system knowledge or action-related knowledge would also lead to a decrease in effectiveness knowledge as indicated by our results. The limited increase and persistence of effectiveness knowledge may also be caused by the programme design and cannot be completely excluded.

As assumed by Kaiser et al. (2008), successful instruction involves not only the students achieving a higher knowledge level, but also a stronger knowledge convergence. Students who participated in our programme showed a tendency towards developing a more integrated knowledge base of system, action-related and effectiveness knowledge from pre- to post- and retention test. To depict the interpretation of our outcome, we employ a metaphorical picture of three circles, with each circle representing one knowledge dimension. Before the programme input, the circles only marginally touch each other, symbolising interrelation (for supporting data, please refer to Table 3) and therefore the mutual interdependence of the knowledge dimensions mentioned earlier. Students' knowledge gain throughout the programme can be imagined as growing circles which overlap. We interpret this overlapping as knowledge convergence, since the knowledge dimensions are mutually interdependent. System knowledge showed the strongest increase, and its corresponding circle therefore has the greatest diameter and also the strongest overlap with the action-related-knowledge and effectiveness-knowledge circles. This picture is in line with our results, since the convergence of system knowledge with action-related knowledge and effectiveness knowledge, as statistically represented by correlation coefficients, shows the greatest increase in integration over the test times. The effectiveness knowledge shows the smallest knowledge-level increase and therefore, using the picture metaphor, its circle overlaps least with the other dimensions. This picture reflects our outcomes since the integration with the other knowledge dimensions, especially action-related knowledge, is smaller. The decrease in knowledge convergence between effectiveness knowledge and action-related knowledge as indicated by the retention test results 4 weeks after programme participation is also noticeable. Effectiveness knowledge shows the strongest decrease after the programme, followed by action-related knowledge. Returning to our picture of circles, we imagine that the decrease in the diameter of both knowledge circles from T1 to T2 may have again led to a decrease in knowledge convergence. Nevertheless, the overall outcome of the programme with regard to knowledge integration is clear.

The data from experts in the field of water would be expected to show a very strong knowledge integration, which would ultimately not allow any distinction to be made between the knowledge dimensions (cf. Frick et al., 2004). As the knowledge dimensions become increasingly interconnected and integrated within a person's knowledge base, they merge together, eventually forming a single knowledge dimension. Our test results suggest that although the 9–13-year-old participants already demonstrate some knowledge integration, further integration of the individual knowledge dimensions is still possible as they continue to learn in the future. Our results indicate that knowledge convergence can be enhanced with educational programmes; however, further research is necessary to confirm our theoretical metaphor of overlapping circles representing the three knowledge dimensions.

Emerging Challenges for Educational Research

The emerging challenges for educational researchers aiming to conduct further research based on the three knowledge dimensions principally occur in two areas: psychological measurement scales and didactic methods.

In the measurement area, the three environmental knowledge dimensions provide very useful information on the educational efficiency of a programme, because they allow the measurement of knowledge convergence in addition to the commonly reported change in a non-differentiated knowledge level. Environmental education programmes that have positive outcomes with respect to both the knowledge dimensions and knowledge convergence can be considered successful. Besides measuring knowledge convergence, the analysis of scales (measurement instruments) with the Rasch model allows researchers to easily assess a scale's quality as well as to differentiate the item difficulties and person abilities, to find outliers and to explain specific outcomes when looking at the scale characteristics (e.g. fit statistic). But, the main advantage of the Rasch model is its 'scale freeness' (Michell, 1986), also called ‘specific objectivity’ in Rasch literature (e.g. Bond & Fox, 2007). This implies that the person order as well as the knowledge increase from studies based on our three knowledge scales can be generalised and replicated with other scales measuring the same dimensions. In other words, person ‘A’ who achieves a higher score than person ‘B’ on our system knowledge scale would also achieve a better score on any other reliable scale constructed to measure system knowledge. Furthermore, the knowledge increase of our sample should also be found by other instruments measuring ‘system knowledge’. Although studies may not be based on the same items, their results are comparable, since person scores (logits) reach interval level by definition of the Rasch model. Further, specific objectivity means that the scale’s item ordering according to the item difficulties can also be reproduced by applying the same items to a sample with a comparable knowledge level. This property of measuring person abilities independently of the specific items and vice versa, calculating the item difficulties independently of the sample, is unique to the Rasch model (Bond & Fox, 2007).

Second, coming to didactic methods, we suggest designing programmes which strongly emphasise all three dimensions, because the dimensions are interdependent. It would be of interest to test various didactic methods, such as learning at workstations (e.g. Sturm & Bogner, 2008), the jigsaw method (e.g. Aronson, 1978), collaborative group discussions (e.g. Mason & Santi, 1998) and role modelling (e.g. Emmons, 1997) to determine their capacities to effectively enhance the knowledge corresponding to the three environmental knowledge dimensions.

Practical Implications for Environmental Educators

Our results suggest that programmes covering all three environmental knowledge dimensions are valuable for increasing the students’ environmental knowledge level and fostering knowledge convergence. This implies that environmental educators should consider these dimensions when designing an intervention. A successful intervention can, for example, start with a system knowledge part (e.g. instruction on facts about virtual water and consequent local and global problems) and then follow with a link to action-related knowledge and effectiveness knowledge. The latter may be achieved by offering actions that students can take to save virtual water as well as each action’s effectiveness. For example, students might learn about the amount of virtual water needed for producing beef (e.g. for watering food plants, as drinking water and for cleaning stables): subject matter about the amount of water needed to produce 1 kg of beef can lead to the acquisition of action-related knowledge (students can make better-informed decisions). Effectiveness knowledge is gained when students compare different kinds of meat regarding their consumption of virtual water during the production processes. The approach does not necessarily need to consecutively follow the three steps mentioned above when an integrative module based on the situated learning theory (Lave & Wegner, 1991) is applied, for example, by employing learning at workstations or the jigsaw method. In conclusion, educational interventions enhancing environmental knowledge require a careful design which emphasises effectiveness knowledge in addition to action-related knowledge and system knowledge. A successful educational unit fosters educational success, which is reflected by an increased knowledge level and stronger knowledge convergence.

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No potential conflict of interest was reported by the authors.

Note

1. The effect size *r* was calculated according to Cohen (1988) with 0.10 as a small effect, with 0.30 as a medium effect and with 0.50 as a large effect.

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Appendix 1. Schedule of the environmental education programme 'Water in Life—Life in Water'

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	*Arrival*	Blue Planet	Life in Water	Water world wide	*Departure*
Afternoon	Observation walk	Stream adventure	*Leisure*	Report of experts and conclusion of long-term task	
Evening	Introduction to the long-term task (expert groups)	*Leisure*	*Night hike*	*Leisure*	

Note: Additional information is written in italics.

Appendix 2. Additional information on the module content, the corresponding Bavarian curriculum and the amount of related environmental knowledge items for each module

Module name	Content[a]	Bavarian curriculum[b]	Related questions
Observation Walk to the Lake[d]	Measurement of water pH and temperature	6.1.1 Form of appearance and properties of water 6.1.2 Water quality	SK02
Long-term Task	Tasks on water usage, water pollution and virtual water[c]	4.5.3 Water supply and wastewater management	SK06 and SK08
		6.1.1 Form of appearance and properties of water	AK02, AK04, AK05 and AK10
		6.1.2 Water quality	EK02, EK04, EK05, EK06, EK07, EK09, EK10

(*Continued*)

Appendix 2. Continued

Module name	Content[a]	Bavarian curriculum[b]	Related questions
Blue Planet	Water chemistry, physics, circulation and sources	4.5.1 The natural cycle of water 6.1.1 Form of appearance and properties of water	SK01 and SK07
Stream Adventure[d]	Catch and identify small water animals[c]	4.5.2 Water as habitat for animals and plants 6.2.1 Animals living in and near the water 6.2.2 Adaption of animals to the habitat water	SK04
Water World Wide	Water distribution, water and climate, sustainability, virtual water, tap water and waste water[c]	4.5.3 Water supply and waste water management 6.1.1 Form of appearance and properties of water 6.1.2 Water quality	SK01, SK06, SK08, SK10 AK01, AK04, AK07, AK09 EK02, EK04 and EK05
Life in Water	Amphibians, plants, food web and more[c]	4.5.2 Water as habitat for animals and plants 6.2.1 Animals living in and at the water 6.2.2 Adaption of animals to the habitat water	SK04 and SK02

Note: SK, system knowledge; AK, action-related knowledge; EK, effectiveness knowledge.

[a] Only content which is relevant for the increase in environmental knowledge is included.

[b] Content which has to be taught according to the Bavarian curriculum of grade 4 (http://www.isb.bayern.de/download/8827/lp_gs_2000_jgst__4.pdf, p. 266f) and grade 6 (*Hauptschule*; http://www.isb.bayern.de/download/13395/03lp_pcb_6_r.pdf, p. 1f); numbers refer to the headings in the curriculum of grade 4 (4.5 Living with nature) or grade 6 (6.1 Water—basis of life, 6.2 Water as a habitat); only the subheading of the curriculum document without the in-depth description is given.

[c] Special country-specific content is included.

[d] Modules with a focus on promoting connectedness to nature (see Liefländer, Fröhlich, Bogner, & Schultz, 2013).