

Outreach Science Education: Evidence-Based Studies in a Gene Technology Lab

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Nowadays, outreach labs are important informal learning environments in science education. After summarizing research to goals outreach labs focus on, we describe our evidence-based gene technology lab as a model of a research-driven outreach program. Evaluation-based optimizations of hands-on teaching based on cognitive load theory (additional group discussions) and on conceptual change theory (consideration of students' alternative conceptions) achieved higher instructional efficiencies. We argue both modifications as generalizable for science teaching. As more general results, we describe identified student cognitive load types and problems of tutoring in hands-on teaching. Finally, we present our innovative approach of combining student and preservice teacher education, theory-based on pedagogical content knowledge by focusing on preservice teachers' change from student, to tutor, to teacher roles.

Keywords: Outreach education, hands-on teaching, cognitive load theory, tutoring, preservice teacher education, pedagogical content knowledge

INTRODUCTION

This special EURASIA issue focuses on recent trends in science education and science education research in Germany. Since the last two decades, many outreach labs provide new and substantial informal learning environments, by offering a great diversity of science subjects (about one third biology) for student target groups (about one third upper secondary students); about one half of such labs are provided with scientific research facilities (see Lernort Labor, 2013). Here, we focus on outreach labs where students conduct hands-on experiments under the guidance of teachers other than the classroom ones (i.e. scientists and/or university teachers). In day-long programs, classes usually complete authentic experiments which are not possible in school, due, for instance, to high costs (e.g. a thermal cycler as deoxyribonucleic acid

amplifier in a polymerase chain reaction) or to legal restrictions (e.g. safety rules; KMK, 2013). Nevertheless, the experiments usually follow the existing syllabi.

Collectively, outreach labs focus on goals at three levels, including students, teachers, and science education research. The first are supposed (a) to promote an increase in students' interest in science, (b) to bring students into contact with authentic experiences in order to acquire scientific knowledge, (c) to face them with an adequate view of science and technology as well as their importance for society, (d) to provide them with specific knowledge about potential career paths in science and technology, and (e) to discuss socially controversial issues (e.g. gene technology; Dähnhardt, Sommer, & Euler, 2007). Second, according to teachers, about one fourth of German outreach labs provide professional development courses for in-service teachers (Lernort Labor, 2013). In our case, teachers completed adapted biotechnology experiments applicable in school. For preservice teachers, about one fifth of the German outreach labs offer appropriate programs, either as integrative modules by individually learning about lab experiments (e.g. in our lab, courses including school experiments in gene technology), or as

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State of the literature

- Outreach labs are important learning environments, focusing on goals relevant for students, teachers, and science education research.
- Student-related goals are often described as promoting students' interest in science and bringing them into contact with authentic experiences, and enabling them to acquire scientific knowledge.
- However, descriptions of well-documented science outreach programs are rare and frequently anecdotal; and most internationally published evaluation studies have been criticized, for instance, for lack of peer review or empirical rigor.

Contribution of this paper to the literature

- We developed our gene technology outreach lab following evidence-based evaluations steps; our lab represents a model of a research-driven outreach program.
- The introduction of a new two-step-approach of experimental phases and the implementation of students' previously gathered alternative conceptions into our teaching units led to higher instructional efficiency, and optimized our hands-on modules.
- Identifying student groups that differently experience cognitive load in lab teaching phases, monitoring specific effects of tutoring and combining student and preservice teacher education showed specific options of evidence-based outreach science education research.

part of compulsory training modules in teaching students (e.g. in our lab, see below). Third, outreach labs have a great potential for science education research, especially for monitoring the goals listed above (e.g. Scharfenberg & Bogner, 2010; for details, see below). Nonetheless, the labs are learning environments where more general science educational research questions may be answered, such as the effects of specific media in the lab context (e.g. animations regarding polymerase chain reaction; Yarden & Yarden, 2010).

The achievement potential through participation in such outreach lab days is a current issue in science education research, although the effectiveness of laboratory work itself has also frequently been acknowledged (for a review, see Hofstein and Lunetta 2004). In the following sections, we first summarize studies examining the abovementioned student-related goals of outreach labs. Second, we regard our evidence-based approach of outreach module development as a potential model of a research-driven outreach program. Third, we present two modification steps as a result of

our program evaluation that empirically based optimized our lab modules and that we argue as generalizable. Forth, we characterize two more general opportunities for science education research offered by our lab, regarding students' cognitive load (CL) during hand-on teaching units and potential effects of tutoring in the lab. Fifth, we look at the prospects of outreach labs for preservice teacher education in the context of pedagogical content knowledge (PCK), and finish with some conclusions.

Research on Outreach Labs

For all these student-related goals, German evaluation studies exist. First, outreach labs have been shown to develop students' situational interest (e.g. Glowinski & Bayrhuber, 2011); especially, the importance of conducting hands-on experiments, of their authenticity (Glowinski & Bayrhuber, 2011), and of students' self-concepts abilities have been demonstrated (e.g. for chemistry, Brandt, 2005; or physics, Weßnigk, 2013). Second, besides our work on cognitive achievement (see below), Glowinski (2007) has reported positive results with respect to self-reported knowledge gains. Additionally, Stolarsky Ben-Nun and Yarden (2009) described the promotion of students' comprehension of concepts in molecular genetics, pointing to a potential conceptual change from alternative conceptions to more scientific ones. Third, for an "industry-oriented lab approach", outreach labs may improve "the image of the 'hard' natural sciences physics and chemistry" (Weßnigk, 2013, p. V). Forth, outreach labs may positively influence students' "career orientation", especially for "technically experienced and keen students" (Weßnigk, 2013, p.VI). Fifth, in discussing socially controversial issues, outreach labs may substantially add to a student's competence in reflecting ethical questions, for instance, within the issue of gene technology (e.g. Glowinski, 2007). Of course, many studies reported results regarding ethical issues in gene technology (e.g. Venville & Dawson, 2010), but studies combining ethical issues and authentic experience are scarce (e.g. in our lab, Goldschmidt & Bogner, 2013).

Many internationally published evaluation studies have been criticized. First, "at present, much of the literature that informs the science learning in informal environments has not undergone a rigorous, systematic peer review" (Bell, Lewenstein, Shouse, & Feder, 2009, p. 304). Second, the publications often lack empirical rigor, "because many of the claims made are not supported by evidence gathered using methodologically based evaluation approaches" (Laursen, Liston, Thiry, & Graf, 2007, p. 50). They contain various flaws such as inhomogeneous student groups (Laursen et al., 2007), lack of repeated measurement (Bogue, 2007), of

measuring students' achievement as outcome (Philipps, Finelstein, & Wever-Frerichs, 2007), or of control groups (Valla & Williams, 2012). Rommel and Hermann (2010) summarized "that there is scant evidence of well-documented science outreach programs" (p. 109), reaching often just an anecdotal level. To avoid these flaws, we opted for a continuous empirically evidence-based evaluation right from the start of our outreach lab.

Formative and Summative Evaluation of the Bayreuth Gene Technology Modules

For more than a decade, the Bayreuth gene technology outreach lab has been in operation, providing three day-long modules: Gene technology – What's that? (grade 10) as well as Marker Genes in Bacteria and Genetic Fingerprinting (grade 12; Table 1). All modules conform to existing syllabi and are considered authentic: They represent the "ordinary day-to-day actions of the community of the practitioners" (Hodson, 1998, p. 118). Additionally, they fulfill the criteria of "authentic inquiry" (Chinn & Malhotra, 2002, p. 118), as for example in the module Marker Genes in Bacteria (Table 2). All modules combine minds-on and hands-on activities (Hofstein & Lunetta, 2004). To avoid students simply acting as recipe followers, specific minds-on phases prior to experimentation are necessary, in order to force students to hypothesize about potential results. Therefore, we embedded a sequence of paired theoretical and experimental phases between a starting pre-lab and a final interpretation phase. The number of pairs is dependent on the number of experiments within the corresponding module (see Table 1). The theoretical minds-on phase of each phase pair provides the scientific background of each experiment by updating students' prior knowledge. The teacher prompts the students to ask questions, to suggest experimental procedures, and to hypothesize about the expected experimental outcomes. Subsequently, the students complete the hands-on experiment of this phase pair in three- or four-peer work groups. After completing the last pair, the final interpretation phase encourages the students to discuss their individual results by taking their previously formulated hypotheses into account. We have published more detailed module descriptions elsewhere (Franke & Bogner, 2011a; Scharfenberg, Bogner, & Klautke, 2007; Scharfenberg & Bogner, 2013a).

Each module was formatively evaluated twice (Table 1). As an example, we describe the evaluation steps of the module Marker Genes of Bacteria. A pilot phase tested different variants of the experiments planned, assessed its practicability, controlled the written work sheets and allowed its optimization. A following quasi-experimental prestudy tested the design of the main

study. For instance, a consistent problem of comparing experimental and non-experimental teaching approaches is the different time exposure of the participants (this has often been ignored, e.g. Yager, Engen, & Snider, 1969). Authors such as Saunders and Dickinson (1976, p. 461) attempted to overcome this dilemma by using actions like "discussion of material presented in lecture", in order to achieve identical time slots. Following this rationale, we included a non-experimental "lab-plus-time" group ($n = 22$) in our prestudy and provided a typical lab working environment in combination with printed information which allowed repetition of the themes taught. However, we did not find any differences in learning outcomes, that is, why we did not include this kind of control group in our main study (Scharfenberg et al., 2007). We also pretested the instruments to examine the students' outcome of the lab day. For instance, a shortened scale adapted from Todt and Götz (2000) for measuring epistemic interest ("the desire to know more"; Euler, 2004, p. 190) turned out to be insufficiently reliable. We therefore followed Rost's (1996) formula to improve reliabilities by extending our scale to nine items in our main study and hence achieving sufficient reliability scores (i.e., Cronbach's Alpha values $\geq .81$; Scharfenberg, 2005).

Finally, we summatively evaluated our modules with regard to cognitive achievement and interest (for details, see Scharfenberg et al., 2007). We applied a quasi-experimental control group design ($N = 337$), including (a) a hands-on group, carrying out the experiments in the outreach lab; (b) a non-experimental laboratory group, taught in a theoretical non-experimental mode in the lab; (c) a school group, taught in a theoretical non-experimental mode at school; and (d) an external group not subjected to intervention and only performing the test schedule. Altogether, higher learning success in the hands-on group (Mann Whitney U test [MWU]: $p = .045$) was coupled with drawbacks such as a higher decrease rate (MWU: $p = .008$; Scharfenberg et al., 2007, p. 35); that is, our results fitted previously found inconsistent results (e.g. Harlen, 1999), reasoned by the complexity of the experimental tasks (Harlen, 1999). In our lab module, task complexity might represent, for instance, reading instructions of previously unknown experiment, manipulating the equipment, and/or discussing the group work with peers. Based on chemistry education research which has suggested a potential overload of students' working memory (Johnstone & Wham, 1982), we considered the CL theory (Sweller, Van Merriënboer, & Paas, 1998) as an appropriate theoretical background (Scharfenberg et al., 2007). Cognitive load "represents the load that performing a particular task imposes on the cognitive system of a learner" (Paas, Van Merriënboer, & Adams, 1994, p. 420). It refers to the mental activity of a

Table 1. Formative evaluation of the gene technology modules

Characteristics	Module		
	Gene Technology–What’s that? ^a	Marker Genes in Bacteria ^b	Genetic Fingerprinting ^c
Target group	Grade 10	Grade 12	Grade 12
Experiments	Enzymatic restriction of plasmid DNA with two selected enzymes Ligation of DNA Transformation of bacteria using a recombinant blue/white screening plasmid Inoculation of the bacterial samples on agar plates	Transformation of bacteria using a recombinant green fluorescent protein coding plasmid Isolation of the plasmid transformed Restriction analysis of the plasmid with three enzymes Visualization of students’ own results by agarose gel electrophoresis.	Polymerase chain reaction of the human minisatellite D1S80 Isolation of students’ own DNA from their oral mucosa cells Visualization of students’ own results by agarose gel electrophoresis.
Optimizing practical work and comprehensibility of written instructions			
Pilot study	Secondary school class, 10 th grade (N=24)	A level molecular biology course, 12 th grade (N=15)	A level molecular biology course, 12 th grade (N=15)
Developing and testing instruments and testing study design			
Pre-study	Five secondary school classes, 10 th grade (N=144)	12 A level biology courses, 12 th grade (N=143)	9 A level biology courses, 12 th grade (N=137)

^aDetailed module description, see Franke and Bogner, 2011a.

^bDetailed module description, see Scharfenberg et al., 2007.

^cDetailed module description, see Scharfenberg and Bogner, 2013a.

Table 2. Authenticity of the outreach module Marker Genes in Bacteria

Criteria for authentic inquiry ^a	Example within the module
Developing relatively complex controls	Testing survival of host bacteria during transformation
Making multiple observations	Observation of transformed bacteria on different media
Complex transformation of observations	Conclusion from agarose gel band pattern to existing restriction sites
Consideration of methodological flaws	Analysis of unexpected results
Developing theories about mechanism	Thinking about mechanism of DNA-uptake during transformation

Note: see Scharfenberg et al., 2007, p. 29.

^aaccording to Chinn and Malhotra (2002).

learner’s working memory (Sweller et al. 1998), which has a limited information capacity (e.g., Baddeley 2010). In order to decrease a situationally arisen cognitive overload during the experimental phases, we decided for specifically optimizing these phases, based on CL theory (Scharfenberg, et al., 2007).

Optimization of the Outreach Modules

A New Two-Step Approach for Experimental Phases in Teaching Science

We developed a new two-step approach for the experimental phases of the lab day and aimed both to increase students’ minds-on engagement, and, in consequence, to reduce students’ CL during these phases. Each experimental phase included two steps

(Table 3). In Step One, after completing the preceding theoretical phase of our minds-on-hands-on pair described above, students briefly discuss the subsequent experimental procedure and its theoretical aspects within their work group and write down their ideas on a worksheet that describes the experimental action sequences. This five-minute discussion may generally implement an additional minds-on engagement into the experimental phases, as opposed to conventional non-two-step experimental phases we applied before (see above). Afterwards, in Step Two, students carry out the experimental procedures (Table 3). Employing a quasi-experimental control group design ($N = 231$), we monitored the effects of this instructional change on two levels: first, in terms of its instructional efficiency and, second, by observing students’ activities during the experimental phases.

Instructional efficiency is a variable in CL-based research, combining data of students' mental effort (ME) as "an index of cognitive load" (Ayres, 2006, p. 390) and of their achievement success (Paas & Van Merriënboer, 1993). An instruction is seen as more efficient if similar effort induces better performance or lower effort leads to similar performance (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). As hypothesized, we found higher instructional efficiency in comparison to the conventional non-two-step mode (MWU: $p = .001$). In particular, cognitive achievement scores demonstrated a positive long-term effect of the two-step approach (i.e., six weeks delay; MWU: $p = .022$; small to medium effect size: $\gamma^* = 0.38$; Hedges & Olkin, 1984). That is, the group discussion (Step One) might have reduced content-specific experienced CL during experimentation (Step Two) and thus, avoided potential overload (Scharfenberg & Bogner, 2010).

Second, we videotaped 20 randomly selected work groups from each instructional approach during their experimental phases (two-step approach: $n = 64$; non-two-step approach: $n = 67$). After categorizing the activities of each student during his or her experimental phases, we analyzed their individual time budgets regarding the category frequencies (in total, 131 students), including in-group interaction, in-group observing, preparing or reworking steps, and experimental steps (for details, see Scharfenberg & Bogner, 2011). Subsequent inter-approach comparison of time budgets showed a higher proportion of in-group interaction within the new two-step approach (Student's t statistics [T]: $t(129) = -10.17, p < .001$), coupled with a decrease in the in-group observing category (T: $t(129) = 8.10, p < .001$). The group discussion in Step One also led to increased in-group interaction while performing the experimental procedures (Step Two), that is, to increased minds-on activities within Step Two. Increasing interaction with high-level elaboration has been argued to be related to cognitive achievement (e.g., Webb 1989). We know about the limitation of our video study: the lack of a transcription analysis with regard to students' verbalizing. However, as we found an increased cognitive achievement, we suggest positive interaction effects and, consequently, regard Step Two as a step of the experimental phase with both hands-on and minds-on activities (Table 3). Additionally, we clustered students based upon similar activity patterns

within the individual time budgets and identified four clusters per approach, each representing one behavioral student type; for instance, all-rounders whose members distributed their time nearly equally over all relevant behavioral activities. Interestingly, observers and high-experimenters were non-two-step-specific types and might be seen as rather undesirable. The high-experimenters clearly dominated hands-on activities (preparing or reworking steps as well as experimental steps) within their work groups. Consequently, some students had only the chance to observe those group members, showing the observer behavioral type. Within the two-step approach, observers and high-experimenters disappeared completely. We found as two-step-specific type managers that demonstrated an especially high proportion of in-group interaction. We presumed a change toward a more "democratic" leadership style occurred where the "group plans and implements as a team" (Gayford 1992, p. 45), induced by our new two-step approach. Thus, implementation of the two-step approach of experimental phases may further develop core competencies in genetics education such as collaboration within a team (NCHPEG, 2007), or the ability to engage in science-related communication (KMK, 2005).

Implementation of Students' Alternative Conceptions

On the basis of their everyday experiences, students have often already developed alternative conceptions on the different science subjects and bring these to the classroom (e.g., Tanner & Allen, 2005). Students' alternative conceptions usually differ from scientific conceptions (e.g., Morrison & Lederman, 2003), especially in the context of genetics. For instance, Venville, Gribble, and Donovan (2005, p. 628) reported for Australian students aged 9 to 15 years that "most students ... did not have a conceptual understanding of what genes ... are or what they do". The conceptual change (CC) theory first presented by Posner, Strike, Hewson and Gertzog (1982) defines four basic conditions for successful CC: If a student experience discomfort with an old conception and a new conception is logical, plausible and fertile, it can be accepted. Previously argued as a radical change (Posner et al., 1982), recent authors regard CC not as a simple

Table 3. Two-step approach of outreach lab modules

Phase	Description	Students' activities
Pre-lab	Introduction to work area	Hands-on
Theoretical phase n_i	From the theoretical background to the students' hypotheses	Minds-on
Experimental phase n_i	Step One: short focused group discussion n_i	Minds-on
	Step Two: performing the experimental procedure n_i	Hands-on and Minds-on
Interpretation	Final discussion of results	Minds-on

Note: n_i describes the repeated sequence of this phase pair according to number of n_i experiments, dependent on the module content.

replacement of alternative conceptions by scientific ones, but as a “different contextual activation of alternative representations” (Vosniadou & Brewer, 1999, p. 5). The consideration of students’ alternative conceptions within teaching is a prerequisite for CC (Posner et al., 1982). Consequently, we suggested consideration of students’ alternative conceptions may also optimize our outreach modules.

According to Chi, Slotta and De Leeuw (1994), conceptions can be determined by categorization. For a successful implementation of students’ alternative conceptions in science teaching, such a categorization is necessary, coupled with an interpretation of the results found. Consequently, we started this optimization step with a pre-study for quantitatively gathering students’ alternative conceptions regarding gene technology ($N = 144$; Table 1). To our knowledge, quantitative research with regard to students’ alternative conceptions within this context has focused on implicitly and unknowingly described student conception data which have indirectly been gathered from knowledge assessments (e.g. Venville & Treagust, 1998). Gene technology which plays a prominent role within genetics was generally not included. We opted for an explicit approach. A half year before participating in the outreach lab, we prompted our students to explicitly describe their conceptions about four terms of gene technology as well as about three gene technology processes. All students were novices in gene technology. Before participation in our survey, they did not have any lesson yet in genetic education at school. We iteratively categorized the students’ descriptions by following the method of inductive category development (Mayring, 2000) and subsequently assigned 13 categories. For example, we identified the category *container* for the term *gene*, that is, the student conception was connected to a container with something inside, and the category *pedigree* for the process *change of genotype*, that is, student conception was connected to words showing relationships (for details, see Franke, Scharfenberg, & Bogner, 2013). Based on our categorization and the frequencies revealed, we combined each three student statements describing different alternative conceptions (as distractors) with the correct scientific conception (as the key for each item; e.g. King, Gardner, Zucker, & Jorgensen, 2004) to a seven-item multiple choice questionnaire (Franke, Scharfenberg, & Bogner, 2013). We applied this questionnaire within the main study described below, in order to examine a potential CC initiated by our modules regarding terms and processes of gene technology.

Strike and Posner (1992) have regarded the acceptance of new scientific conception as dependent on a cognitive conflict with individual alternative conceptions. A suitable teaching strategy is the constructivist teaching sequence (Driver, 1989). After a

first orientation phase, there follow an elicitation phase of students’ conceptions and a subsequent restructuring phase of selected conceptions. During these phases, a process of clarification and exchange occurs, where single conceptions conflict with each other to allow the construction of new conceptions. An application phase of the new conceptions follows accompanied by an assessment of potential changes (i.e. review of change in ideas) and a subsequent comparison of the new and old conceptions. We implemented such a constructive teaching sequence in our module Gene Technology – What’s that (see Table 1), specifically using the previously gathered alternative conceptions (as mentioned above). Applying a quasi-experimental control group design ($N=293$), we examined the effects of this instructional change at three levels: first, in terms of its instructional efficiency, second, in terms of CC, and third, in terms of situational emotions.

First, as hypothesized, we found a higher instructional efficiency for the implementation approach in comparison to the control group without the implementation of students’ alternative conceptions. Independently, long-term (six weeks delay) cognitive achievement increased in both groups (Wilcoxon test [W]: $p < .001$), although the treatment sample was more instructionally efficient, in both the short term (posttest after intervention) and the long term, especially, in the interpretation phase (MWU: $p < .001$ & $p = .04$; for details, see Franke & Bogner, 2011a). Second, with regard to CC, we monitored the frequency of alternative conceptions in a pre-, post- and delayed post test, applying the questionnaire based on our pre-study results (see above). In the long-term, students in the implementation approach abandoned more alternative conceptions in favor of scientific conceptions (MWU: $p = .02$). Furthermore, an unexpected gender effect appeared: In the short-term, more boys shifted toward more scientific conceptions (W: $p < .001$). Girls gave up their alternative conceptions also in the long-term (W: $p < .001$), independently of the applied instructional method (for details, see Franke & Bogner, 2011b). Third, students’ situational emotions within the implementation approach scored higher in the positive emotions interest and well-being (MWU: $p < .01$) while the negative emotion anxiety did not occur in either group. Furthermore, we found a potential influence of interest and well-being on cognitive achievement. Students who felt fine and worked with interest scored higher in the cognitive achievement test (MWU: $p < .001$; for details, see Franke & Bogner, 2013).

More General Chances for Science Education Research Provided by an Outreach Lab

As written above, outreach labs may be learning environments for more general science educational

research; for instance, with regard to the research question “for whom specific instructional manipulations are effective and why” (Goldman, 2009, p. 452). In this section, we describe two options to answer this question, in part: first, pointing to the “whom”, in this case based on a specific CL research approach, and second, pointing to one “specific instructional manipulation”, in this case tutoring as instructional change.

Student Cognitive Load Types Identified by Cluster Analyses

Since the beginning of our research, we have focused on students’ experienced CL during participation on our gene technology modules (see above). Sweller, Van Merriënboer, and Paas (1998) have differentiated three CL components: (a) intrinsic CL as caused by the complexity of the content to be learned. Within gene technology education, one may assume a relatively high content complexity; therefore students may experience a correspondingly high intrinsic CL. (b) Extraneous CL refers to the instructional mode and does not positively contribute to the students’ learning and, in the worst case, may even hamper it. (c) Germane CL is necessary for individually processing information and transferring it to long-term memory, thereby enabling learning. With respect to CL theory, De Jong (2010, p. 126) recently recommended research that estimates which processes “are most suited for which learners so that the experienced CL is optimized and cognitive overload is avoided”. To answer this question, a first step might be to classify students according to their experienced CL. Identifying student CL groups on the basis of their potentially differing CL experience during the different module instructional phases (Table 3) might give insights not gained otherwise. For instance, performing an experimental procedure might be argued to be a “learning environment” where “extraneous load can be inextricably bound with germane load” (Paas, Renkl, & Sweller, 2004, p. 3). In comparison to a minds-on phase, students might experience an increased extraneous CL during hands-on activities, presumably caused by students’ hands-on-specific tasks, such as reading the instructions (e.g. Scharfenberg et al., 2007). We hypothesized that students might differ in that experience, and that each module phase might produce different student CL groups. Additionally, other students might differ in the overall level of CL, experienced during all four module instructional phases. Members of different CL groups might also differ in some learner characteristics. Consequently, we monitored students’ ME during the module phases (Table 3) as well as learner characteristics (e.g. epistemic interest), laboratory variables (e.g. cooperation in student work groups), and cognitive achievement by

using a pre-post-follow-up design (one week before; six weeks delay; $N = 409$; for details, see Scharfenberg & Bogner, 2013a). Applying cluster analyses to the students’ module-phase-specific ME pattern, we first extracted three CL clusters which were independent of the module instructional phases, labeled as low-level, average-level, and high-level loaded clusters. Second, we identified two student CL clusters that were each particular to a module phase. Their members reported especially high ME invested in one phase each: within the pre-lab phase and within the interpretation phase. For instance, high-pre-lab-loaded students were characterized by two learner characteristics, a low uncertainty tolerance coupled with low prior experience in experimenting within science education at school (MWU: p values $< .04$). According to these characteristics, perhaps better “element-by-element” (Ayres, 2006, p. 289) learning is preferable for high-pre-lab-loaded students, for instance by employing additional tutors. Analyzing the differences between all clusters, we identified uncertainty tolerance, prior experience in experimentation, epistemic interest, and prior knowledge as relevant learner characteristics. Additionally, relationships to cognitive achievement exist, but none to the examined laboratory variables (for details, see Scharfenberg & Bogner, 2013a).

Tutoring in Science Education

Many outreach labs use tutoring as instructional approach (e.g. Engeln, 2004). Following Kersaint, Dogbey, Barber, & Kephart (2011), we define tutoring as an approach where a tutor “supports and promotes the learning” of tutees (p. 26). Within outreach labs, different variants of supporting students during experimental phases exist (Engeln, 2004). Our students complete their experiments as independently as possible. According to the classification of teacher interventions described by Leiß and Wiegand (2005), the teacher “does not intervene until the students seem to stop working because of several ... mistakes” (p. 242). Additionally, he or she intervenes if students are about to endanger an experimental result by making an unrecoverable mistake. Other outreach labs provide one of the two possible models of tutoring to the student work groups, according to Hock, Deshler, and Schumaker (1999): assignment-assistance tutoring and instructional tutoring. In the first model, a tutor only offers assistance “based on the assignment or task that the students bring to the tutor’s attention” (Kersaint et al. 2011, p. 26), that is, the tutor only acts on a student’s request. In contrast, in the second model, an instructional tutor “instruct[s] the student[s] through explanation, modeling, and guided practice”, thus keeping “the student[s] academically afloat” (Kersaint et al. 2011, p. 26; originally emphasized).

Kersaint et al. (2011) have argued that tutoring is effective in facilitating a student's learning, but simultaneously they complained an under-researched situation for tutoring tutees' hands-on activities. For instance, Glowinski (2007) described the quality of tutoring as relevant to students' epistemic interest and to their self-reported knowledge gain, but without explaining in detail how tutoring was organized. Based on CL theory, we hypothesized that implementing tutoring into the module's pre-lab and experimental phases (Table 3) might overcome the described student problems. For instance in the pre-lab phase, tutors might reduce students' experienced extraneous CL by providing hands-on help. Additionally, tutors may positively affect both the hands-on and the minds-on levels of the experimental phases. They might reduce the students' experienced extraneous CL by providing hands-on help (as in the pre-lab phase). Furthermore, answering students' content-specific questions might lower the experienced intrinsic CL at the minds-on level. Thus, students might allocate more of their working memory to germane CL, thereby avoiding a potential overload. We therefore hypothesized that the newly developed tutoring approach (see below) would be more instructionally efficient, compared to the previously applied non-tutoring approach.

We tested our hypotheses by applying a quasi-experimental control group design ($N = 269$; for details, see Scharfenberg & Bogner, 2013b). While the control group followed the non-tutoring approach previously used, the treatment group was subjected to the newly developed tutoring approach. To avoid bias, we first selected tutors with similar scientific backgrounds. Second, we prepared all the tutors together; for instance, prior to their tutoring day, they completed one lab day in the role of school students. At the end of this lab day, the teacher and the prospective tutors reflected on all the experiences with regard to the following tutoring day. According to the assignment-assistance model of tutoring (Kersaint et al. 2011), the teacher highlighted two tutoring rules: providing assistance to the students only (a) if the students explicitly request a tutor activity either by asking a question or by soliciting a tutor's help or (b) intervening if the students are about to make an unrecoverable mistake that would adversely affect the experimental result. Each tutor was responsible for two student work groups and recorded his or her tutoring activities as requested by the tutees throughout the day (in total, 436 activities). We measured the students' invested ME, cognitive achievement (in a pre-post-follow-up design; for time spans, see above), the students' cooperation in their work groups, and calculated their instructional involvement (as a motivational variable). Additionally, we examined which aspects of the hands-on phases were of particular relevance to the students' invested ME. Unexpectedly,

our tutoring approach resulted in lower instructional efficiency (MWU: $p = .001$ & $p = .033$), despite the relevance of tutoring for students' ME invested during the experimental phases (contingency coefficient $c = .217$; $p < .001$). In the examined variant, all the hypotheses have to be rejected. The tutoring approach was not the more efficient approach as expected; indeed, it was found to be less efficient than the non-tutoring approach. Surprisingly, it also influenced the theoretical phases, that is, the students in the tutoring approach experienced a lower CL in these phases (MWU: $p = .001$). As possible reasons, we considered that (a) students as tutees might primarily consider the tutors as additional sources of information, which they consult in the majority of cases without any real need; that (b) students unexpectedly invested less ME in the theoretical phases only, perhaps in anticipation of the tutor's minds-on help later in the experimental phases; that (c) the tutors might have reinforced the students' status as help seekers by their, in part unnecessary, non-student-requested tutor interventions: Nearly two thirds of these non-student-requested interventions were interventions concerning the experimental procedures or the equipment. That is, the tutors did not conform to the second rule for tutoring. Despite of having been instructed about this rule, our university students did not completely follow it when subsequently acting as tutors. This corroborates the observations of Arrington, Hill, Radfar, Whisnant, and Bass (2008) who also found their tutors as not playing the tutor role as expected. The authors conclude that for future projects, their tutors should "not [to] be allowed to touch the glassware – only to advise" the tutees (Arrington et al. 2008, p. 289).

In summary, we suggest that our results indicate three important learner characteristics relevant to tutoring student experiments in science education, independent of the lab setting (both in an outreach lab and at school): (a) The learners request unnecessary information; (b) other information they request earlier than needed; and (c) they are, in part, less motivated. All three characteristics may result from the students' anticipation of the tutor's help at both the minds-on and the hands-on levels. Consequently, tutoring approaches have to take these characteristics into account to make the students more responsible for their cognitive achievement. Tutors generally face the "assistance dilemma ... between information giving and withholding" (Koedinger and Alevan 2007, p. 242). They should not react too early when students request help. For instance, tutors should not immediately answer every question at the minds-on level, but return it to the requesting work group. As for requested hands-on help, tutors should first of all focus students' attention on their group members. Such a change in the tutor's behavior may promote more links between

students' minds-on and hands-on activities during experimentation. Thus, tutors may act more as thinking catalysts for the students rather than only as answer providers or procedural helpers. A potential approach to changing tutors' behavior might be to implement role playing with both student and tutor roles during the tutor preparation phase. We suggest that such a change in our tutoring approach would be more efficient for students' learning.

Outreach Labs and Pre-service Teacher Education

As mentioned above, about one fifth of German outreach labs regards preservice teachers as target group (Lernort Labor, 2013). Haupt et al. (2013, p. 327) categorized such labs as teaching-and-learning outreach labs ("Lehr-Lern-Labore"), usually provided by universities. However, peer-reviewed publications concerning combining outreach student teaching and preservice teacher education are scarce. For instance in chemistry education, Steffensky and Parchmann (2007, p.123) described that their preservice teachers, after an initial theoretical phase, first "observe school classes" in the outreach lab, then, in tandems, repeatedly "work with groups of children"; and finally, "develop an experiment or a series of experiments that can be integrated in the course in the future". However, they did not test their planned experimental series. Based on qualitative analyzes ($N=15$), the authors concluded that the preservice teachers assessed the repeated "working with 'real' children" as an important element in the educational design (Steffensky & Parchmann, 2007, p. 124).

We also categorize our outreach lab as teaching-and-learning lab. We combined our preservice teacher module Learning and Teaching in an Outreach Lab (Table 4) with the student module Genetic

Fingerprinting (Table 1). We based our module development on the theory of PCK. Beside subject matter knowledge and pedagogical knowledge, PCK has been regarded as one essential part of a teacher's professional knowledge (e.g. Abell, 2008). PCK is considered as a "special amalgam of content and pedagogy" (Shulman, 1987, p. 8) and has differently been conceptualized (for review, e.g. Park & Oliver, 2008). Following chemistry education researchers (e.g. De Jong, Van Driel, & Verloop, 2005), we opted for the multidimensional PCK conceptualization of Magnusson, Krajcik, and Borko (1999) as the basis of our module development. The authors differentiate, based on a teacher's "orientation to science teaching", between "knowledge of science curricula, of students' understanding of science, of instructional strategies, and of assessment of scientific literacy" as PCK components (Magnusson et al., 1999, p. 99). However, they point out that one preservice teacher education module cannot support all PCK components in the available time (Magnusson et al., 1999). Consequently, we decided to focus on specific PCK aspects in our module (Table 4). To assure sufficient content knowledge as a prerequisite, we choose graduate preservice teachers as our target group (actually first term of Master of Education in biology education). They were all graduates in both microbiology and genetics modules as well as in the basics of biology education. Our initial theoretical seminar focuses, besides updating preservice teachers' content knowledge, on the following PCK aspects: (a) knowledge of the current curriculum; (b) knowledge of identified, content-specific alternative conceptions of the students (e.g. Franke, Scharfenberg, & Bogner, 2013; StolarskyBen-Nun & Yarden, 2009) as part of the "requirements for [students'] learning" for "students' understanding of science"; and (c) knowledge of possible "representations" and "activities" as part of the

Table 4. The pre-service teacher educational module Learning and Teaching in the Outreach Lab combines pre-service teacher education and student science education

Pre-service teachers' work group	Module	
	Phase	Content
Group as a whole	Theoretical preparation	Updating and developing knowledge about the scientific content, the current curriculum, known content-specific student alternative conceptions, the module's student experiments, and potential teaching aids ^a
Group as a whole	Practical preparation	Building up the eight student work group areas (for a maximum of 32 students)
Four-person group	First experimental day	Participation on the student module as eighth 'student group'
Four-person group	Second experimental day	Participation on the student module as tutor for two student work groups
Four-person group	Third experimental day	Participation on the student module as teacher for the pre-lab phase or one experiment (theoretical and experimental phase), in the other phases as for two student work groups
Group as a whole	Follow-up seminar	Final reflection of the experiences made by changing the roles

^aFor instance, models, animations or other media.

“instructional strategies” (Magnusson et al., 1999, p. 99), that is, content-specific media as teaching aids and possible experiments. After the necessary practical preparation (building up students’ work areas; Table 4), the preservice teachers randomly join four-person groups for the following three experimental days in the lab. As our innovative contribution, we implemented a preservice teachers’ role change: from the student role on the first day, to the tutor role on the second day, and, finally, to the teacher role on the third day. The three roles may provide the possibility to appreciate potential learning difficulties of the students and to develop potential instructional strategies to handle these difficulties, due to different points of view (see below). On their first day, the preservice teachers participate on the student module as an additional ‘student group’, that is, they start in the student role. In order to perceive potential learning difficulties by themselves as learner, they complete the pre-lab phase, the theoretical phases and the combined experiments; and they interpret their results in the final interpretation phase. On the second day, our preservice teachers are engaged as tutors responsible for two student work groups, that is, they change to the tutor role. Again, they may perceive potential student learning difficulties, in this case from the tutor’s point of view, in the pre-lab and the experimental phases; and they may reflect upon any difficulties experienced in planning their third day as teacher, in order to develop corresponding instructional strategies for at least one hands-on phase. On the third day, the preservice teachers change to the teacher role. They have to teach either the pre-lab phase or one of the three theoretical and experimental dyads, thereby potentially applying their ideas of instructional changes to avoid the student difficulties experienced the two days before. Within the other phases, they again perform the tutor role. A final reflection seminar finishes the module. The preservice teachers together with the mentor discuss all experiences based on the role change regarding learning difficulties and instructional strategies.

Regarding PCK development in teacher education programs, Grossman (1990) pointed to four potential sources: (a) underpinning subject matter knowledge as a necessary prerequisite; (b) observing students in real teaching situations; (c) the possibility of teaching students by him- or herself; and (d) participation in teacher education courses which may potentially affect teachers’ PCK by linking “reflection ... to the practical realities of classroom teaching” (Grossman, 1990, p. 144). We suggest that our module fits these prerequisites of PCK development. Therefore, we propose that our preservice teachers might successfully develop PCK with changing from a student, to a tutor, to a teacher role. Preliminary explorative evaluations pointed to such effects. Within a pre-follow-up design (six weeks delay),

our pre-service teachers quite differently addressed potential student learning difficulties. For instance, the importance of students’ prior knowledge was underestimated. As soon as sufficient empirical numbers are achieved, results will be published in detail elsewhere.

CONCLUSIONS

In line with the objectives of this special EURASIA issue, we provided an overview about using outreach labs as recent trend in German science education. By describing our formative and summative steps of module evaluation, we argue our Bayreuth gene technology lab as a model for a research-driven outreach program. Regarding our optimization changes, we recommend both our two-step approach of the experimental phases in a lab unit, and our implementation of previously gathered student alternative conceptions into our teaching unit for any experimental teaching in science. Evidence-based, the two-step approach positively effected teaching in our outreach lab. We suggest that similar effects will occur if one would employ this approach in science education, independently of the lab setting (outreach or school lab) and of the science subject being taught (e.g. biology, chemistry, or physics). Regarding the implementation of students’ alternative conceptions, our results concur with to the body of previous research done in classrooms (e.g. Venville & Treagust, 1998). Again, the positive effects we found suggest the possibility of similar effects in other hands-on units, independently of the lab setting and the science subject. In summary, we here see two generalizable outcomes of our science education research in an outreach lab.

Regarding more general opportunities an outreach lab offer for science education research, we focused on both identifying student CL types, and potential effects of tutoring in a lab teaching unit. First, at a methodological level, clustering students due to their invested ME during different phases of a learning unit may generally allow more insight into students’ CL during science teaching in comparison to usual mean score analyses, independently of our hands-on outreach approach. Second, the identified clusters underscore the importance of the teacher’s attention to pre-lab and interpretation phases of hands-on teaching in science education. Independently of the lab setting (outreach or school), we generally assume that teachers might encounter specifically high-loaded students who need help in those module phases which confront them with a new experimental issue. For instance, for the pre-lab phase in science education lab settings, “time is often too scarce” for previously developing the necessary skills; and “for mainly economic reasons” teachers often forego such a pre-lab phase (Winberg and Berg, 2007, p.

1111). Consequently, we recommend the investment of more time in preparing pre-lab and interpretation phases. Third, our tutoring results underscore the importance of the teacher's attention to his or her role while teaching during student experiments. Independent of the science subject and of the lab setting, teachers need to organize experimental phases so that students cooperatively experiment in small groups. Consequently, the teacher has to change his or her classroom teacher role to a tutor role, equivalent to the role our tutors adopted in the lab. Thus, he or she also faces the assistance dilemma (Koedinger & Aleven, 2007) and has to be aware of the three learner characteristics identified (see above) in order to appropriately react to them.

Finally, we argue combining student and preservice teacher education in an outreach lab as an approach specifically offering chances for preservice teachers' professional development. Especially, we see our preservice teacher education module with changing roles as model for teaching-and-learning labs, in order to (a) exemplarily develop PCK and (b) focus on preservice teachers' view on this component of a teacher's professional knowledge.

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