Learning in botanical gardens: Investigating educational methods during an instruction about *Plants and Water*

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For all children and adolescents, who are not privileged to participate in education.

For my guardian angels, my family and my beloved husband.

CONTENTS

SUMMARY

The contribution of botanical gardens to out-of-school education should be larger than it is currently in Germany. In the curricula of all school types botany plays only a minor role, although plants form the base for all animal life on earth. To increase the attractiveness of botanical gardens for teachers, offers and programs should be created and conducted in didactically sensible manners and allow students an emotional approach towards the topics through trial and experiments. Therefore it is insufficient to conduct guided tours, which are still most common. Student-centered methods, like learning at workstations, or experimental courses, can lead to an improved retention of the contents learned at the out-of-school learning setting. There are, however, methodological differences even within learning at workstations.

In the first part of my study I compared a student- (S) and a teacher-centered (T) type of learning at workstations (chapter III). My intention was to find out, which of both methods results in more positive emotions at the out-of-school learning location and a higher sustainable knowledge increase. Like in all three parts of my study, 8th grade students from so-called “Mittelschulen” and “Realschulen” from Lower Franconia participated in the programs. I evaluated them by using multiple-choice tests assessing the students' knowledge regarding the topic 'plants and water' (see Appendix), following a before-after / control-impact study design. The students' emotions were assessed using the intrinsic motivation inventory directly after the garden visit. Using generalized linear mixed models, I did not find a significant difference between either of the two approaches. A reason for this could be that the students could be practically active in both methods, which made them fairly similar. Given that there was a significant knowledge increase in both methods, and the effort to develop the teacher-centered learning at workstations was much lower, I would suggest to follow that method for educational work in botanical gardens.

Students already have many predefined concepts regarding many topics, especially when these are important in everyday life. These concepts do often not match the scientific state-of-the-art. Still, students bring their so-called 'alternative conceptions' into visits to the botanical garden. According to theory, confronting them with their own conceptions in the light of scientific facts, should foster updating their concepts with scientifically correct additions. To investigate this method regarding my topic 'plants and water', I developed an

intervention with experiments on the lotus effect, which also plays a role in everyday life (chapter IV). Topics like the surface tension of the water, which is also found in 6th grade curricula in German schools, were included. Prior to the intervention, I assessed the students' conceptions using questionnaires and used the three most frequent alternative conceptions to develop a multiple-choice test, which was also used in a before-after / control-impact design. A group of students was also confronted with their conceptions during an introductory talk (AC), whereas another was not (NAC). This was conducted in a way, that likely led to dissatisfaction of the students with their own concepts. The analysis of the questionnaires with the Mann-Whitney U test showed, however, no difference between the two groups directly following the treatment. Over longer time, however, the NAC group retained significantly more knowledge. Probably the students confronted with the alternative conceptions remembered the illustrations of these more easily than the scientifically correct view. For some botanical topics it is certainly helpful to include this conceptual change approach, but apparently not for the lotus effect. In this case it is most sensible to focus on the surface structure of water-repellent leaves and fruits, as we describe it in a publication in 'Unterricht Biologie'. For the practical work in botanical gardens I would suggest to rather assess the students' concepts and assumptions in the beginning of an intervention in a botanical garden, especially with respect to feasibility.

In the third part of my study I concentrate on the application of concept maps (chapter V). This method of cross-linking old and newly acquired knowledge is effective, but not very common in Germany, neither in schools, nor in botanical gardens. One group of students followed exclusively a teacher-centered learning at workstations regarding 'plants and water' (NCM), a second group created concept maps directly after the treatment and a second directly before the retention test (CM). The first map was intended to be a means of consolidation, whereas the late map was rather focused on recapitulation of what was learned about six weeks ago. To evaluate that I used the same multiple-choice tests as I did for the first part. The CM group showed a significantly higher knowledge increase, over short and long time-scales, although these students did significantly worse in the pretest than those of the NCM group. Regarding genders, female students profited especially from the first concept map (consolidation), males rather from the second (recapitulation). From the results one can conclude that prominently weaker students benefit from this method. Additionally the gender-related results show that using concept maps multiple times can be beneficial for different types of learners.

In every study there also was a control group (C), which only had to fill out the questionnaires at the same time as the participating students, to account for external factors (like media, etc.).

Especially learning at workstations and concept maps are very appropriate to be conducted at the out-of-school learning location botanical garden and are likely to strongly increase learning success. It is beneficial to mix several methods to achieve the best results in different types of learners. Additionally, when methods in school are mixed with those of out-of-school learning, the education gets more open, practical and colorful. That all resulted in a substantial long-term knowledge gain of all participating students.

ZUSAMMENFASSUNG

Der Beitrag botanischer Gärten zur außerschulischen Bildung sollte größer sein, als er momentan in Deutschland ist, denn in den Lehrplänen aller Schularten spielt die Botanik eine sehr geringe Rolle, obwohl Pflanzen die Grundlage allen tierischen Lebens sind. Doch um diesen Lernort für Lehrer attraktiver zu machen, sollten die Programme und Angebote didaktisch aufbereitet sein und den Schülern durch Ausprobieren und Experimentieren einen emotionalen Zugang bieten. Hierfür genügt es nicht, Führungen und Lehrervorträge durchzuführen, welche noch immer zu hohen Prozentsätzen stattfinden. Schülerzentrierte Methoden, wie das Lernen an Stationen, oder experimentelle Praktika, können dazu führen, dass das am außerschulischen Lernort (ASL) Gelernte besser im Gedächtnis bleibt. Jedoch gibt es auch beim Lernen an Stationen methodische Unterschiede.

Im ersten Teil meiner Studie habe ich eine schülerzentrierte (S) gegen eine lehrerzentrierte (T) Form des Lernens an Stationen gegeneinander getestet (siehe Kapitel III), um herauszufinden, welche der beiden Methoden zu positiveren Emotionen am ASL und einem erhöhten, anhaltenden Wissenszuwachs führt. Wie bei allen drei Teilen meiner Studie nahmen Schüler und Schülerinnen der 8. Jahrgangstufe von Mittel-und Realschulen aus Unterfranken teil. Evaluiert wurde mithilfe eines selbst entwickelten Multiple-Choice-Tests zum Wissen der Schüler und Schülerinnen zum Thema Wasser und Pflanzen (siehe Appendix 5). Dieser Test erfolgte als Vor- und Nachtest sowie als verzögerter Behaltenstest (retention). Die Emotionen der Schüler und Schülerinnen wurden über den IMI-Fragebogen (intrinsic motivation inventory) direkt nach dem Besuch im botanischen Garten einmalig erfragt. Weder beim Wissenstest, noch bei den Emotionen, ergab sich nach Auswertung mittels generalisierter gemischter linearer Modelle (GLMM) ein klares Signal für eine der beiden Methoden. Ein Grund könnte sein, dass bei beiden Formen des Lernens an Stationen die Schüler und Schülerinnen auch praktisch aktiv werden konnten, sich die Methoden somit sehr ähnelten. Da bei beiden Methoden insgesamt signifikant dazu gelernt wurde und das eher lehrerzentierte Lernen an Stationen nicht so aufwändig war in der Entwicklung wie das schülerzentrierte, würde ich den botanischen Gärten erstere Methode für die Bildungsarbeit empfehlen.

Schüler und Schülerinnen haben zu vielen Themen, vor allem des Alltags, bereits ganz eigene Konzepte und Vorstellungen, die nicht unbedingt denen das aktuellen

wissenschaftlichen Standes entsprechen. So kommen die Schüler und Schülerinnen natürlich auch mit diesen individuellen Konzepten in den botanischen Garten. Hier sollte nun auch auf diese sogenannten "alternativen Konzepte" eingegangen werden, da diese Konfrontation, laut Theorie, die Übernahme neuer, wissenschaftlich korrekter Bausteine in das bereits vorhandene Konzept fördern soll. Um bei dem Thema Wasser und Pflanzen zu bleiben und gleichzeitig ein alltagsrelevantes Thema anzusprechen, habe ich ein Praktikum und Experimente zum Lotuseffekt entwickelt und die Vorstellungen der Schüler und Schülerinnen dazu erfragt (siehe chapter IV). Hierbei spielten auch Themen wie die Oberflächenspannung von Wasser eine Rolle, was in Deutschland in der 6. Klasse angesprochen wird. Aus nicht korrekten Vorstellungen wurden die drei häufigsten ausgesucht und daraus ein Multiple-Choice-Test entwickelt, der ebenfalls als Vor-, Nach- und Behaltenstest fungierte. In einem einführenden Vortrag zum Lotuseffekt wurde ein Teil der Schüler und Schülerinnen (AC) zusätzlich mit diesen alternativen Vorstellungen konfrontiert, über Bilder und im Unterrichtsgespräch. Dies erfolgte in einer Art und Weise, sodass die Schüler und Schülerinnen mit der eigenen Vorstellung unzufrieden wurden. Eine zweite Gruppe wurde während des Vortrags nicht mit ihren alternativen Vorstellungen konfrontiert (NAC). Die Auswertung der Fragebögen über den Mann-Whitney U Test ergab keinen Unterschied zwischen den beiden Gruppen im Hinblick auf den kurzfristigen Wissenserwerb. Die Gruppe jedoch, welche nicht mit ihren alternativen Vorstellungen konfrontiert wurde (NAC), lernte langfristig im Vergleich zu der AC-Gruppe signifikant mehr dazu. Womöglich erinnerten sich die Schüler und Schülerinnen der AC-Gruppe nur noch an die Bilder der falschen und nicht an die der wissenschaftlich korrekten Vorstellung und wurden somit irritiert. Bei einigen botanischen Themen ist es sicherlich von Vorteil, die alternativen Vorstellungen der Schüler und Schülerinnen einzubringen, vielleicht nicht unbedingt beim Lotuseffekt. Hier sollte man sich, wie in einem von uns dazu verfassten Artikel in der Unterricht Biologie beschrieben sein wird, auf die Oberflächenstruktur von wasserabweisenden Blättern und Früchten beschränken. Für die pädagogische Arbeit in botanischen Gärten würde ich die mündliche Abfrage der Vorstellungen und Vermutungen der Schüler und Schülerinnen zu Beginn eines Programmes aus Gründen der besseren und schnelleren Umsetzbarkeit empfehlen.

Im dritten Teil meiner Studie beschäftigte ich mich mit der Anwendung von Concept Maps (siehe Kapitel V). Diese Methode des Vernetzens von altem und neu erworbenem Wissen ist effektiv, aber weder in deutschen Schulen, noch in botanischen Gärten weit verbreitet. Eine Gruppe folgte ausschließlich dem lehrerzentrierten Lernen an Stationen zu

Wasser und Pflanzen (NCM), eine zweite Gruppe erstellte direkt im Anschluss an das lehrerzentrierte Lernen an Stationen sowie direkt vor dem Behaltenstest eine Concept Map (CM). Die erste Map diente hierbei als Sicherungsform des gerade Gelernten und die späte Map als Wiederholung des vor circa sechs Wochen Gelernten. Als Evaluationsinstrument diente erneut der eigens entwickelte Multiple-Choice-Wissenstest aus der ersten Teilstudie. Die CM-Gruppe zeigte einen signifikant größeren Lernzuwachs, kurz- wie auch langfristig, im Vergleich zur NCM-Gruppe, obwohl die CM-Gruppe im Vortest signifikant schlechter war. Im Hinblick auf die Geschlechter haben die Mädchen vor allem von der ersten Sicherungs-Map und die Jungen mehr von der Wiederholungs-Map profitiert. Anhand der Ergebnisse kann man schlussfolgern, dass vor allem schwächere Schüler und Schülerinnen von dieser Methode profitieren. Außerdem zeigen die Ergebnisse zu den Geschlechtern, dass das mehrmalige Anwenden von Concept Maps unterschiedliche Lerntypen fördern kann.

Bei jeder der drei Studien gab es eine Kontrollgruppe (C), die ausschließlich die Fragebögen im Abstand von sechs bis acht Wochen in der Schule beantworten musste. Dies diente dem Ausschließen von Vorkomnissen in der Öffentlichkeit und dem Umfeld der Schüler und Schülerinnen, was deren Wissen zu Wasser und Pflanzen und dem Lotuseffekt hätte erheblich steigern können.

Vor allem das Lernen an Stationen sowie die Concept Maps lassen sich sehr gut am ASL botanischer Garten durchführen und können zu einem größeren Lernerfolg führen. Am besten spricht man hier die meisten Lerntypen an, wenn man während der Programme möglichst viele verschiedene Methoden anwendet. Dazu kommt, dass man neben den Methoden aus der Schule natürlich auch die des ASL einbringt und so der Unterricht automatisch anschaulicher, offener und praktischer wird. Dies alles hat dazu geführt, das alle Gruppen langfristig signifikant dazu gelernt haben.

Chapter I Botanical gardens and their contribution to out-of-school education

"I hear – I forget.
I see – I remember.
I do – I understand." (Confucius)

Botanical gardens worldwide have the facilities to meet the requirements raised by Confucius to allow for meaningful learning. They harbor plants from all over the world as well as animals (native and non-native), forests, meadows, greenhouses and so on. Hence, botanical gardens are - in contrast to historical, mineralogical and some natural museums - "living museums", where education can be performed in much more practical ways through the direct experience of nature. Furthermore they have the know-how about biology, especially botany, available. Unfortunately, the educators working there often have no educational profession. Kneebone (2007) found that only 19% of the educators of their evaluated gardens were qualified to teach. This could be the reason why in 92% of 107 botanical gardens guided tours, and in 78% talks and lectures, are mainly used as educational methods. Only 63% offered workshops and 52% offered training courses to their visitors. The composition of the latter methods assumes a more didactical know-how and is more time-consuming than those mentioned before. Following these methods the students' thinking and acting take center stage and are called student-centered. There are several studies showing for out-of-school learning locations that student-centered education with hands-on elements - called learning at workstations similar to workshops - leads to a higher learning success than classical teacher-centered lessons, like lectures or guided tours (Thair & Treagust, 1997; Scharfenberg, Bogner & Klautke, 2007; Randler, Kummerer & Wilhelm, 2011). They also improve intrinsic motivation in classrooms (Schaal & Bogner, 2005; Sturm & Bogner, 2008). If we now follow the results of these studies and the conclusions of Confucius, it is desirable to foster methods including hands-on and inquiry-based elements in botanical gardens, rather than relying on guided tours. The studies I conducted in this respect contribute to an enhanced understanding of the value of student-centered approaches. I did not repeat tests of guided tours against learning at workstations. Instead, I focused, among other topics, on the comparison between a teacher-centered (guided) and a student-centered (self-determined) learning at workstations (for details see chapters II and III).

Both of these treatments regarding the topic *plants and water* were practically oriented and the students could partly act on their own. Similarly, in a second part of my study, focused on the lotus effect, the students had to conduct scientific experiments autonomously (chapter IV). Thus, the implementation of the lessons was strongly oriented on Confucius' perspective.

This hands-on approach is for teachers in the daily school life often not or only hard to realize. Hence, out-of-school learning locations like botanical gardens or laboratories are important and helpful facilities that should increasingly be used by schools. Therefore it is necessary for the botanical gardens to improve and extend their especially practical offers for school classes and improve cooperation with schools. In practice this is difficult, because many (48) of the botanical gardens in Germany feature *green schools* (or similar institutions), but only 15 of them have one or more hired pedagogues. Finally, the goal of botanical gardens is, or at least should be, to meet the 14^{th} requirement of the GSPC. The GSPC is the Global Strategy for Plant Conservation and a part of the Convention on Biological Diversity passed by the United Nations in 1992 in Rio de Janeiro. The 14^{th} requirement says that “the importance of plant diversity and the need for its conservation (needs to be) incorporated into communication, educational and public-awareness programs”. But to meet this satisfactorily every botanical garden in Germany should employ at least one pedagogue in full time and should additionally use pedagogy students (see below).

To achieve a higher involvement into the education of students in schools, it is also necessary to make use of more professional educators. Half of the botanical gardens in Germany belong to universities (http://www.verband-botanischer-gaerten.de, accessed 14 July 2014). Thus, many of the learners in these institutions also are university students (Kneebone, 2007). This fact allows for the possibility to let the school students be taught by university students, as it is done in the LehrLernGarten of the University of Würzburg. The university students there learn in seminars how to didactically prepare the topics. However, to my knowledge, this concept is rarely made use of in Germany.

Botanical gardens are very suitable out-of-school learning settings, not only to inform about, but also to experience, botany and nature, allowing for changes in the students' environmental behavior and attitudes (Fančovičová & Prokop, 2011; Johnson & Manoli, 2011). That is why a higher consideration of education at botanical gardens in the German daily school life would prove very helpful in achieving an optimal education. In German syllabuses for all school types of the secondary school phase, botany is rarely mentioned. Only for natural science subjects at the 6th grade there is a recommendation to go to botanical gardens. However, at these learning locations teachers of many subjects have different possibilities for education as Mazor and colleagues showed for one day with 7th grade students in Brooklyn Botanic Garden (Mazor, 2011). As in the gardens different vegetation is shown on very different soils and kinds of rocks, also geographical education can be assisted there. Often mathematical patterns, like the golden ratio or the Fibonacci numbers, are evident in plant growth forms and flowers (Camazine et al., 2003). This might allow to show students about the application of mathematics using systematic courses in botany. With regard to chemistry, one could focus on complex chemical compounds produced by plants, used for ecological interactions. These compounds, e.g. essential oils, can be used by medicine. Gardens also offer opportunities for teaching arts. Besides letting students draw plants or landscapes, they can produce land art with natural materials.

But the botanical garden of the 21st-century should not only educate about these “classical curricular themes”. Also sociocultural topics, like fair trade and the conservation of resources and nature, should stand in the focus. This is often already happening. According to Kneebone (2007) the topic mentioned most often in 90% of the botanical gardens is plant diversity. This is immediately followed by conservation, ethnobotany and endangered species. Rather rare climate change, water conservation, fair trade and social change stand in the focus. Willison demanded in 2006 that botanical gardens should educate about environment and sustainability, but from a didactic perspective these should not be the main focus. There are other governmental or non-governmental organizations (e.g. Greenpeace) that inform about these topics. In my opinion the strength of botanical gardens is that they offer promising opportunities to inspire students through the direct experience of natural phenomena and thus are able to change their attitudes, especially towards botany and conservation (see also chapter III).

CHAPTER II INTRODUCTION TO THE APPLIED METHODS

1. WHAT IS MEANT WITH LEARNING AT WORKSTATIONS IN SCIENCE EDUCATION?

The term “workstation” is a widespread term. It is often used in the context of learning stations in libraries or for computational and IT education, where the students go from computer to computer to deal with several topics. Since the comeback of the pedagogical reform in the 1970s in Europe, workstations as an open and student-centered instructional type (Killermann, Hiering & Starosta, 2008), gained a new meaning and were introduced into “flexible” classrooms, especially in primary schools (Bauer, 1997). Workstations in that sense go back to Helen Pankhurst's “subject corners”, which were developed as a student-centered and individualistic instruction method, in the 1920s. After the implementation of closed curricula in the 1960s the understanding of “learning at workstations” from educational reformers like Célestin Freinet, Peter Petersen and Maria Montessori was brought back into schools. “Learning at workstations” is characterized by a student-centered, cooperative and a self-determined function. The students work independently in small groups at various workstations, where self-instructional material is provided. They also usually get a workbook, leading the group members through the workstations. After handling all workstations the students correct themselves with workbooks, which provide the correct answers, or in a consolidation discussion with the teacher. The teacher acts as a *supporter* at the working phase (Schaal & Bogner, 2005). “The specific value of the learning at workstations is that the students could work self-guided, at their own pace” (Sturm & Bogner, 2008, p. 942) and corresponding to their individual abilities. For fast learners often additional workstations are offered. Learning at workstations produces an open learning environment, which is defined as student-centered (Bauer, 2003). With all those characteristics the method is in line with the self-determination theory (SDT, Ryan & Deci, 2000) and fosters the students' individual experiences of autonomy, competence, and social relatedness. As a consequence, learning at workstations should positively effect the intrinsic motivation of the students. For my first study (for more details see chapter III), additionally to knowledge tests, I used the intrinsic motivation inventory (IMI) developed by Deci and Ryan in 1985 to evaluate my applied workstations.

In science education the workstations contain hands-on, inquiry-based activities and experiments. That makes this method more student-centered and practically oriented in terms of Confucius. It also provides a good opportunity to introduce practice the methods of natural scientific work. Hence, problem-solving skills and the critical thinking of the students are supported and promoted, which should be a goal of the scientific subjects (Taraban et al., 2007).

The hands-on elements could positively affect (besides higher knowledge scores) the motivation of students, as Sturm and Bogner (2008) shown in their study. In contrast to that, Gerstner and Bogner (2010) found no differences for the intrinsic motivation and newly acquired knowledge for the long-time period between a hands-on student-centered and a teacher-centered approach. That shows that the method of learning at workstations does not only have advantages, but also disadvantages. If the method is new to the students and they are not used to this kind of instruction, they will be overstrained. As a consequence the students are stressed by the interaction with the other group members, by the open time frame and hands-on activities per se. However, the participants of my study were no novices for this kind of method. Furthermore, there is a risk of boredom (Schaal & Bogner, 2005) at this instruction when the students have to wait for the next free workstation. This could influence the intrinsic motivation negatively. We tried to minimize this effect with enough hands-on material and an additional seventh workstation (see chapter III).

1.1 Differences between the applied guided and self-determined learning at workstations

For the research described in chapters III and V, I developed a learning at workstations instruction about *plants and water* for mid-level 8th graders and arranged this in the tropical greenhouse of the botanical garden at the University of Würzburg. This *self-determined learning at workstations* included all of the four major parts Randler and Bogner (2009) used for their *modern approach*:

a. experiments concerning, for example, *Clematis vitalba* L., *Nymphaea spec.* (Fig. 2.1), and hands-on elements at the workstation regarding the transpiration of *Ocimum basilicum* L. and the water transport in vascular strands of *Apium graveolens* L.,

b. media like original objects, magnifying glasses, illustrations etc. (Fig 2.2)

c. a reduced impact of the teacher and

d. group sizes of 3-5 students to create a cooperative learning environment.

Figure 2.1: *A student conducting one of the experiments of the learning at workstations program. Therefore she blows into the stem of Nymphaea spec.*

Figure 2.2: *Material, illustrations and information of one of the self-determined workstations program.*

My *guided learning at workstations*, according to Heyne and Bogner (2012), differs in the two latter aspects. At this treatment the teacher leads a bigger group of students (approx. 15) from the first to the last working station and acts as *moderator* and not as *supporter,* as in the second approach. That is why we defined the *guided learning at workstations* treatment as teacher-centered and the other one as student-centered. The *moderator* discusses the tasks and problems with the students, which they should solve or find out, to notice the results in an own workbook (see Appendix 1). These workbooks were not the same as those of the *self-determined learning at workstations* (see Appendix 2). The working stations had the same topics, the same hands-on materials, experiments and illustrations (see Appendix 3). However, the difference was that the teacher explained the illustrations and biological relationships to the students. Consequently, the teacher-centered students did not have to read as much as those in the student-centered treatment. It is possible that not every participant of the bigger teacher-centered group experimented and tried out, although the students were admonished by the teacher. Furthermore, these students had to follow the teachers pace and had no choice, which station they want to handle first.

In contrast to the study design by Randler and Bogner (2009), my treatments do not differ in every of the four major parts, necessarily leading to less strong results. However, for reasons of scientific logic, we aimed at not changing too many parameters at once. Furthermore, classical guided tours in botanical gardens, in which students can not touch anything, are anyways not very frequent anymore.

2. Conceptual Change – not only a theory

On the basis of the work of some researchers in the 1970s about students' scientific (mis)conceptions, Posner, Strike, Hewson & Gertzog (1982) established the *theory of conceptual change* and specified four conditions for the accommodation of conceptual change. The authors follow the assumption that the learning process is a result by what children are taught and what ideas and concepts they bring to the classroom (Ausubel, 1968). Those ideas and concepts are often in contrast to the common scientific views and theories. Changing these *misconceptions* (Helm, 1980) or *alternative conceptions* (Murphy & Alexander, 2008) is a great challenge for educators, because these conceptions are *highly robust* (Viennot, 1979). Posner et al. hypothesized that the changing process could only occur if the following four conditions were considered:

a. The students must be dissatisfied with their current concept about a topic so that a cognitive conflict arises. Thereupon the students have to see the necessity to learn something new and probably discard old ideas.

b. The new concept must be intelligible for the student. The new concept has to be structured and presented in a way that allows for fast accommodation and comprehension through the student.

c. The new concept must be plausible. The new concept has to be consistent with other existing knowledge about the topic and should help to solve the posing problem.

d. The new concept should be fruitful, i.e. enabling the students to explain already known or new scientific phenomena.

This is at least the theory, but what does it meant for educational practice in science?

Research of conceptual change is dominated by the scientific disciplines. This could be due to the fact that these disciplines and their hypothesis-driven research are basically a form of conceptual change (Posner et al., 1982). Hence, especially in science subjects the use of the conceptual change theory is appropriate. Apart from that many studies in the last three decades have shown that this constructivistic approach has a positive influence on cognitive knowledge (Duit & Treagust, 2012). Still, knowledge about and education on these learning and teaching methods are not very pronounced in teachers. Among these constructivistic methods generally have a low reputation. Thus, this way of instructions is rarely, if at all, made use of (Duit, Treagust & Widodo, 2013). This is, however, also not easy to achieve in daily school life: 1. the students have to be fetched from where they are, 2. they have to be confronted with their individual alternative conceptions, 3. the scientific view must be introduced in a demonstrative, intelligible and plausible way.

Thus, at first the teacher needs to know the students' conceptions, so he / she has to ask for them. While this is generally easily possible at the beginning of a lesson, e.g. through confrontation with a problem or a natural phenomenon with a discussion, it is not easy to assess every individual conception this way. Therefore the teacher would have to conduct interviews, let the students create concept maps (Mintzes, Wandersee & Novak, 2001) or fill out questionnaires, at the beginning of each large section in the subject (like genetics, evolution or photosynthesis in biology). This is, of course, not possible given the high numbers of students and classes, every teacher would have to take care of. However, asking for conceptions (or hypotheses) at the beginning of a lesson and subsequent testing of these according to the natural scientific way of research would at least be a start. Using this evaluation method the question "how do I confront the student with his / her alternative conception?" would also not be relevant anymore.

Several other methods have successfully been used for the creation of cognitive conflicts in previous studies regarding science education, like refutation texts (Mason, Gava & Boldrin, 2008), pictures (Franke & Bogner, 2011a) and computer animations (Çalik, Kolomuç & Karagölge, 2010). Figures, originals and texts are certainly easy to integrate into a lesson, but therefore the alternative conceptions must already be known to the teacher. Social scientists and psychologists demand an individual confrontation with concepts. Hence they do not expect collecting the most common alternative conceptions and applying them in a generalized form for all students. However, such an individualistic approach is neither in every day school life, nor in rather quantitative studies like the one presented in chapter IV applicable. Following the confrontation phase the challenge is to make the students familiar with professionally correct contents, which allow for a conceptual change. For this step refutation texts have already been successfully applied (Guzzetti, Snyder, Glass & Gamas, 1993; Mason et al., 2008). Vosniadou and Ioannides (1998) and Vosniadou, Ioannides, Dimitrakopoulou & Papademetriou (2001) advised against this method, as it might confuse students and thus lead to contradicting conceptions. Because of that and in the course of practically oriented and constructivistic science education it is, however, desirable to rather make use of models, originals, experiments and hands-on elements with discussion (Van Driel, 2002; Franke & Bogner, 2011a), as I also did in the approach presented here (chapter IV). An aggravating factor for the teacher is that the conceptual change of students is also affected by emotions, motivation and social aspects, which also have to be acknowledged (Duit & Treagust, 2012).

That a teacher manages all these factors and dares to follow the conceptual change theory requires a very good education and strong dedication of the teacher. It would also be very helpful for teachers and instrumental in the use of this method, if scientific studies regarding conceptual change would be of a rather practical and applied nature (Duit & Treagust, 2013). We tried to achieve this in a study regarding the lotus effect and bionics in the botanical garden of the University of Würzburg (chapter IV). Additionally, the lessons created therefore and the conceptions assessed from the students are part of the teachers' education in Würzburg. This lesson will in a modified version be published in an article, which will not be described in detail, here (Heyne & Kubisch, in press).

3. Concept mapping

3.1 Concept mapping – a method for every opportunity

Concept mapping is a popular research topic in education. This is certainly supported by the fact that concept maps can be analyzed quantitatively and qualitatively. It can be combined with other methods and is often used as an evaluation method of instructions (Schaal, Bogner & Girwidz, 2010; Muscat, 2013; Judson, 2012). But what are the attributes of this method? A concept map is a diagram, which represents organized knowledge (Novak & Gowin, 1984; see Fig. 5.2). The smallest unit of a concept map is the *proposition.* A *proposition* is a meaningful statement and consists of two concepts and a link (Fig. 2.3). Concepts are usually single words of an event or an object, although sometimes symbols are used as well (Cañas et al., 2003). The connecting link is an arrow with describing words to specify the relationship between the two concepts. Cross-links between several of those meaningful *propositions* result in different types of submaps, like chains, spokes and nets (Kinchin, Hay & Adams, 2000; see Fig. 2.4). Those submaps create a concept map with an often hierarchical structure.

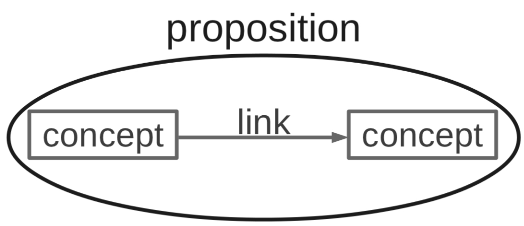

Figure 2.3: *A proposition, the smallest unit of a concept map.*

The main goal of the application of concept maps is to foster *meaningful learning* (Cañas et al., 2003). The assimilation theory of *meaningful learning* proposed by Ausubel (1968) is based on the assumption that "meaningful learning occurs when learners connect new information to the existing knowledge structure" (Gurlitt & Renkl, 2010). Therefore, three requirements have to be fulfilled: 1. relevant prior knowledge, 2. meaningful material, and 3. the learner must choose to learn meaningfully (Novak & Gowin, 1984). Joseph D. Novak, the developer of concept maps in the 1970s, believed that these tools fulfill the above requirements (1998).

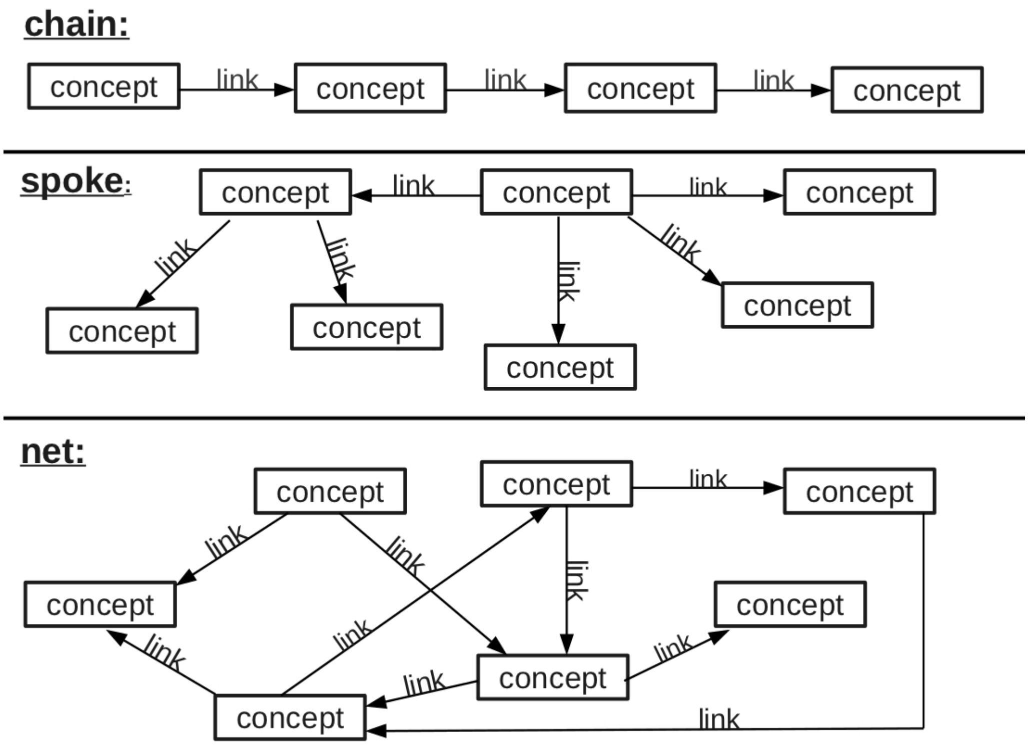

Figure 2.4: *Possible appearance of three different submaps (chains, spokes and nets), according to Kinchin et al. (2000).*

Looking at the literature one could assume that the method of concept mapping is the method of choice for every subject and circumstance. It is successfully used in science education, as for example in mathematics (Brinkmann, 2003), biology (Kinchin, 2011) or chemistry (BouJaoude & Attieh, 2008), as well as in English lessons (Khodadady & Ghanizadeh, 2011). There concept maps are extensively used for numerous educational applications: 1. as a scaffold for understanding, 2. as a tool for the consolidation of educational experiences, 3. as a tool for improvement of affective conditions for learning, 4. as an aid or alternative to traditional writing assignments, 5. as a tool to teach critical thinking, 6. as a mediating representation for supporting interaction among learners, and 7. as an aid for the process of learning through teaching. (Cañas et al., 2003).

Hence one could expect that concept mapping is for every opportunity a promising method and should always be more successful as conventional methods with regard to fostering knowledge and understanding. Especially, there are some studies indicating that lower ability learners profit even more by the use of this method (Haugwitz, Nesbit & Sandmann, 2010; Udeani & Okafor, 2012). I applied concept maps in the study presented in chapter V as a means of consolidation and recapitulation to measure the effect of the cognitive learning success after a guided learning at workstations about *plants and water*.

3.2 The difference between consolidation and recapitulation

Many recent studies applied concept mapping as a consolidation tool (Esiobu & Soyibo, 1995, Conradty & Bogner, 2010; Gerstner & Bogner, 2010; Kinchin, Streatfield & Hay, 2010). Some researchers, however, called it repetition (Lumer & Hesse, 2004). But "repetition is more a means to reach consolidation" (Cicognani, 2000). In my study on concept mapping (see chapter V) I used the method directly after an instruction to consolidate and deepen the new knowledge. Consequently, the students repeated the content of the instruction with the help of concept mapping. The same group created a second concept map six weeks after the instruction, as a recapitulation tool. With this concept map I did not want to reach a consolidation of knowledge. This second concept mapping phase should rather support the remembering and refreshing of the "old" knowledge so that the students could reach better results in the cognitive test afterward. As to my knowledge there is no study, where concept mapping was applied in that way, and thus there is a lack in literature about concept maps as recapitulation tools, I was interested in whether concept mapping is helpful therefore or whether it confusing for the students.

4. Statistical methods

In this section I will provide a brief overview of the main statistical methods used in this thesis. According to the nature of the data different methods have been applied. I further used the R language for statistical computing (R development core team, 2012) for all analyses. In the following descriptions of the methods I also list all relevant R commands that have been used within this thesis.

4.1 Classical Tests

Mann-Whitney U test

The non-parametric Mann-Whitney U test is also called Wilcoxon rank-sum test or Mann-Whitney-Wilcoxon test. With the U test the medians of two independent samples are compared. One condition to use this test is ordinal scaled data. Such data can be sorted in a ranked order, but there is no information about the relative degree of difference between the values. An attribute with a high rank has a high value and vice versa, for example dichotomous data as 'right' or 'wrong', 'thick' or 'thin' or non-dichotomous data like 'gold', 'silver' and 'bronze'. A second condition for using the Mann-Whitney U test is that the distributions of the compared subsets of the data should have the same form. If both distributions do not overlap each other the resulting *U*-values are highly different, thus the null hypothesis can be rejected. The null hypothesis is that the medians of two independent samples do not differ, whereas the alternative hypothesis is that the medians of two independent samples differ. The calculation of the *U*-values is based on the assignment of ranks for each observation in one of the two samples and the summation of the ranks:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

with n_1 (and n_2) denoting the size of samples 1 (and 2) and R_1 and R_2 giving the sums of the ranks within the two samples. After calculating both values, the smaller one is the used test statistic (in R given as *W*) and the probability of getting this or a larger value under the assumption of the null hypothesis is calculated (Wilcoxon, 1945).

The R-code for the calculation is: `wilcox.test(x,y)`

In the present study I used this test to assess, whether the instructional methods differed with regard to the medians of the knowledge scores of the students (see chapters IV and V). Furthermore the Mann-Whitney U test was used to compared the total knowledge score differences between the three test times (see chapter V), because the samples were independent, the sample size was small and the data were not normally distributed.

Wilcoxon signed rank test

In contrast to the Wilcoxon rank sum test the Wilcoxon signed rank test assesses, whether the medians of two dependent samples differ from each other. Therefore the data have to be interval scaled and again the distributions of the subsets have to be of the same form. Interval scaled data are data where the distances between the attributes can be calculated exactly, for examples body height, age and temperature. To conduct the Wilcoxon signed rank test one first has to calculate the absolute differences $|d_i|$ between all paired observations i. These differences now get sorted from the lowest to the highest value and ranks R_i are assigned. The sign of the ranks is given by the sign of the corresponding difference d_i. The final test characteristic W is now given by:

$$W=|\sum_{i=1}^{n} sgn(d_i)\cdot R_i|$$

with n denoting the sample size and *sgn* being the sign function (Wilcoxon, 1945).

For this test the null hypothesis is that the median difference between the observations is 0. Accordingly the alternative hypothesis is that the median difference between the observations is not 0.

The R-code for the calculation is: `wilcox.test(x,y,paired=T)`

This test is used in this thesis to test, whether the students learned from the pre- to the posttest and from the pretest to the retention and if they forgot from the posttest to the retention (see chapters IV and V).

Bonferroni-Holm correction

Many studies want to answer more than one hypothesis. As a consequence classical tests are used to compare samples multiple times. This is a problem, because multiple comparisons increase the probability of statistically significant results. Hence the null hypothesis will with a higher probability be rejected falsely, which is an error type 1. The Bonferroni-Holm correction (Holm, 1979) is one way to minimize the probability of such errors. The method provides a stepwise algorithm. The first step is to determine a global significance level α_G. Afterwards all k tests are performed and the resulting p-values sorted from the lowest to the highest. The local significance level for test i, α_i (with i denoting the position of the test in the described sorted list) is then given by:

$$\alpha_i = \frac{\alpha_G}{k-i+1}$$

with k denoting the number of performed tests.

In chapters IV and V the results of the three test times are compared multiple times with Wilcoxon signed rank tests, as described before. Here the Bonferroni-Holm correction is by default applied by the R command `pairwise.wilcox.test(x,g,paired=T)`, which performs Wilcoxon signed rank tests of data x for each possible pairing of groups g, which were pretest, posttest and retention in my case.

4.2 Generalized Linear Mixed Models

Linear Models

Linear models define the relationship between an independent variable x and a dependent variable y (Fig. 2.5). The basic linear equation is:

$$y = \beta_0 + \beta_1 \cdot x$$

with β_0 giving the intercept and β_1 the slope of the relationship.

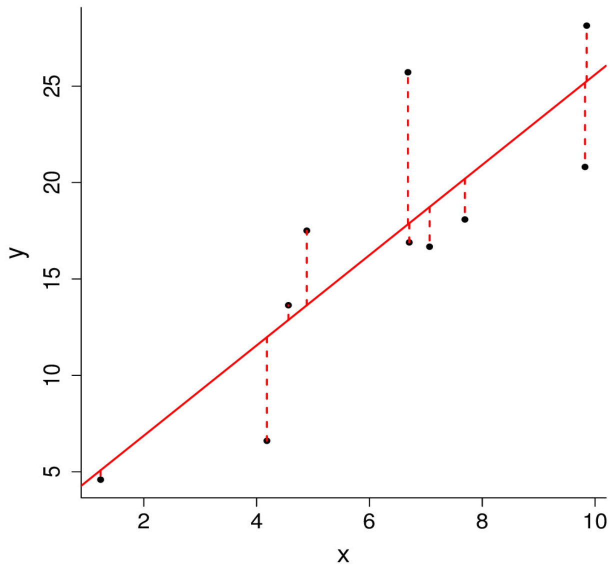

Figure 2.5: *Example data set with y being dependent on x. The solid red line shows the best-fit linear model. The dashed red lines visualize the residuals.*

The problem is that real data rarely follow a straight line. Linear regression offers a method to fit a linear model to a given set of data and thus allows to determine the best-fit line. To find the parameters β_0 and β_1, which determine the optimal model, the residual sum of squares is minimized. Residuals are the unexplained deviations of the data from those values predicted by the model (Fig. 2.5). Thus, the amount of unexplained variation of the data can not simply be the sum of residuals, as some of them are positive and some are negative. The squared values are always positive. The formula of the statistical model is given by:

$$y=\beta_0+\beta_1\cdot x+\epsilon$$

with ε being the error distribution of the residuals.

As can intuitively be seen in the above equation, it is without any problems possible to include multiple explanatory variables into a linear model. It might even happen that they interact with each other. It could for example be that female students perform better under treatment A, while male students perform better under treatment B. This would mean an interaction between gender and treatment. Mathematically, this interaction is given by the product of the according variables. Assuming two explanatory variables x1 and x2 a full linear model can be formulated as:

$$y=\beta_0+\beta_1\cdot x_1+\beta_2\cdot x_2+\beta_3\cdot x_1\cdot x_2+\epsilon \quad .$$

For the through the so called 'least - square fitting' determined parameters β to be sensible, several assumptions must be fulfilled. These are that 1. the independent variable is determined exactly and only the dependent variable is measured with errors, 2. these errors (residuals) follow a Gaussian distribution and 3. the variance of this distribution is constant across the range of the independent variable.

These assumptions show clearly that linear regression could not be the method of choice for the data I assessed for the studies of this thesis. I analyzed the sums of correctly answered questions of students under several treatments. Evidently, this sum comes in discrete values and can not be lower than 0, thus the assumption of a normal error distribution is violated. Therefore, I had to use a generalized modeling approach, which I will describe in the following.

Generalized linear models (GLM)

Generalized linear models provide the opportunity to investigate the relationship between a dependent and one to more independent variables for several types of error distributions. In the following I will narrow this method's description to the analysis of Poisson distributed data, as this is, what I performed for this thesis.

The basic idea behind GLM is to map the discrete non-negative values of the dependent variable to a continuous space of values by using a link function. In the case of the Poisson distribution this link is given by the natural logarithm. It is important to note that this does not mean a transformation of the dependent values but that the logarithm of the observed values depends on the independent variables. Consequently, given that the exponential function is the inverse to the logarithm, a basic formulation of a GLM in case of Poisson-distributed data is given by:

$$y = e^{\beta_0 + \beta_1 \cdot x_1} + \epsilon \quad .$$

What can not be seen in the above equation is that the least square method I described for the linear regression does not work for this GLM. In fact, the named method was a special case for something called a maximum likelihood approach. The likelihood describes the probability of the parameters β being true given the data x and y. It is thus clear that those values for β provide an optimal fit of the function, for which this likelihood is maximal. R obtains these by starting with some arbitrary parameter values, calculating the likelihood given the data and mutating the parameters afterwards. Then the likelihood for the mutated parameters is compared to the previous one. If the new one is higher, the according parameters are conserved and mutated by themselves. This procedure is repeated a lot of times until an equilibrium is achieved. The final parameters define the model, which describes the data with maximal likelihood.

Mixed effects models

The data I obtained in my studies were necessarily influenced by factors I was scientifically not interested in. These factors, which were present due to my nested experimental design, needed to be included in the statistical analysis. In contrast to the variables I was interested in, the so called fixed effects (e.g. the treatment), they are called random effects. This means that in my case a student's identity within a specific class within a specific school might all influence the results. Yet, their direct effect was irrelevant for my research topic. Mathematically, these random effects influence the intercept of a model. A model, which contains both fixed and random effects, is called a mixed effects model. In a hypothetical case of one fixed and two nested random effects, such a model can be formulated as:

$$y_{ij}=\beta_0+\beta_1\cdot x+u_i+w_{ij}+\epsilon$$

with y_{ij} being the value of the dependent variable for observation ij (e.g. the sum of correct answers of student j in school i), x denoting the fixed effect (e.g. the treatment) and u_i and w_{ij} giving the random effects. In our example, u_i can e.g. be the difference between school i's mean from the global mean and w_{ij} the difference between class j's mean and school i's mean.

Generalized linear mixed models (GLMM)

In my studies I both had to deal with random effects, caused by the hierarchical experimental design, and data, which follow a Poisson distribution. Thus, to investigate the influences of my treatments, I had to make use of a generalized and a mixed model approach. This can simultaneously be done within the framework of generalized linear mixed models. In case of a Poisson distribution these can accordingly have the following basic formulation:

$$y_{ij}=e^{\beta_0+\beta_1\cdot x+u_i+w_{ij}}+\epsilon \quad .$$

Model selection using the AIC

Of course it is necessary to determine the relative influence of the fixed factors and to exclude unimportant parameters from the model that should explain the data. To do so one needs some statistic that summarizes the goodness of fit of the model. One statistic commonly used for that is the Akaike information criterion (AIC), which is calculated as:

$$AIC=-2LL+2k$$

with LL being the logarithm of the model's likelihood and k being the number of parameters in the model. The idea behind is that models with many parameters can explain a lot of variation, but come at the cost of clarity and understanding. Thus, the model with a high likelihood and a low number of parameters is considered a good model. It is clear from the equation above that the best model will have the lowest AIC.

According to Zuur et al. (2009) I performed stepwise model selection based on the AIC. This means that I started with the full model including all random and fixed factors including interactions. Then I stepwise excluded factors, recalculated the AIC and compared it to the more complex model version. Repeatedly performing this procedure allowed me to find the optimal model.

Calculating GLMMs in R

A GLMM analysis can in R be performed using the package “lme4” (version 0.999999). The command used to implement a GLMM is:

```
m1 <- lmer(y~x1*x2+(1|u1/u2),family=poisson).
```

Here, y is the dependent variable, which depends on (~) the fixed factors x1 and x2 as well as their interaction (the '*' means that both factors and their interaction are simultaneously considered) and the random factors u1 and u2 with u2 being nested within u1. The error distribution is given by the family argument.

4.3 Questionnaire quality assessment

The best statistical method is of limited usefulness for scientific purposes, if the gathered data are of poor quality. In the studies I present in this thesis, I assessed the knowledge of students using questionnaires. This means that the quality of the data is determined by the experimental design on one hand (which is in detail described in the respective chapters) and by the quality of the questionnaires on the other hand. A variety of methods has been developed to assess the quality of questionnaires, two of which I will describe here. Note that the first method (Cronbach's α) has been widely criticized, which is why I decided to rely on the results of the second method (comparison to the Rasch model).

Cronbach's α

One very important characteristic of questionnaires is their internal consistency. This describes the correlation between the items (i.e. questions). If several items of a questionnaire address the same topic (say, e.g., the understanding of a basic biological principle like photosynthesis) and are answered similarly the internal consistency of the questionnaire can be considered to be high and the results meaningful. In 1951, Lee J.

Cronbach proposed a test statistic to assess the internal consistency of questionnaires. The value of α can be calculated as:

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} \sigma_{Y_i}^2}{\sigma_X^2}\right)$$

with K denoting the number of items, σ^2_{Yi} giving the variance of any item i among the answers provided by the tested persons and σ^2_X denoting the overall variance in the observed test scores. Thus, by calculating α and therefore using the observed variation in test scores for every single item and all items together, internal consistency is in general said to be assessed. According to Lienert & Raatz (1998), values for Cronbach's α between 0.5 and 0.7 generally allow for the differentiation between groups.

Critics of Cronbach's α

In recent years, Cronbach's α has been increasingly criticized for actually not assessing, what it is intended to as described above. Sijtsma (2009) wrote that all that α can assess is the average interrelatedness between items, but that this measure is not necessarily connected to internal consistency, which by itself is unclearly defined. He further notes that, as Nunnally (1978) has shown before, α increases, when the number of items increases. Evidently, a larger questionnaire does not automatically imply a 'better' questionnaire with higher reliability.

Following the argumentation of Sijtsma, a whole range of values for Cronbachs α can be calculated for questionnaires with high and low internal consistency or high and low unidimensionality (see below). He even writes that the “only reason to report alpha is that top journals tend to accept articles that use statistical methods that have been around for a long time such as alpha” (Sijtsma, 2009, p. 118).

Yet, additional methods for the assessment of the quality and reliability of questionnaires have been proposed, which are of higher usefulness than α. I focused for my analysis on applying the Rasch model, which I will therefore describe below in its fundamental assumptions.

The item response theory

An alternative approach to assessing the quality of questionnaires is given by the item response theory. In contrast to methods of classical test theory, like Cronbach's alpha, this theory focuses on the quality (and thus also difficulty) of single items, not on that of the whole test. Item response theory follows a probabilistic approach, as the idea behind is that the probability of any item's answer is a mathematical function of an individual's ability and the item's difficulty.

Three assumptions form the base of item response theory:

1. A unidimensional trait is considered, which may be denoted by θ.
2. Items are locally independent.
3. A person's potential response to an item can be modeled by an item response function.

The trait here describes a so-called 'latent' characteristic of the tested persons, e.g. their intelligence or specific knowledge on a topic, so actually the trait that is about to be measured. Unidimensional means here that this trait can be assessed solely with the items, without the necessity of a high ability in another trait. An example could be that the mathematical intelligence of a person could be tested without requiring high abilities in language.

That items are locally independent means that every item needs to stand for its own - the probability of answering correctly to this item should not depend on the ability to answer any other item.

The Rasch Model

The Rasch model, as the most famous approach within item response theory, describes the probability of correctly answering an item as a function of a persons' and the item's characteristics. I focus here on the dichotomous formulation of the Rasch model, which allows only two types of answers to items: 0 and 1 (i.e. wrong and correct). This is the formulation I needed to test the quality of the questionnaires used in my studies.

For the dichotomous Rasch model one considers a number of n persons participating (every single person denoted by v) and answering k items within the questionnaire (every single item denoted by i).
In that case, the probability p_{vi} of person v giving a specific answer x_{vi} to item i is given by:

$$Pr(X_{vi}=x_{vi}|\theta_v,\beta_i)=\frac{\exp(x_{vi}(\theta_v-\beta_i))}{1+\exp(\theta_v-\beta_i)}=p_{vi}$$

with x_{vi} denoting the respective answer per person v and item i (so x_{vi} is either 0 or 1), X_{vi} denoting the random variable describing the yet unknown answer x_{vi}, θ_v denoting person v's ability and β_i describing the difficulty of item i.

As it is known from theory, the conditional probability of one event occurring, given some conditions (in this case θ_v and β_i), is the probability of this one event happening divided by the sum of the probabilities of all possible events. This is exactly, what is calculated in above equation, as the probability of a wrong answer of an item, i.e. $x_{vi} = 0$, is given by $\exp(0(\theta_v - \beta_i))$, which is exp(0), which is 1, while the probability of success ($x_{vi}=1$) is $\exp(\theta_v - \beta_i)$. Thus, the probability of one given answer x_{vi}, given a specific person's ability θ_v and a specific difficulty of an item i, β_i, is provided conditionally by the probability of this event divided by the total probability of 0 and 1 events given the specific parameters.

The dichotomous Rasch model can be visualized with the so-called item characteristic curve (ICC), which provides for a given item difficulty β_i the relationship between the probability to solve an item as a function of a person's ability:

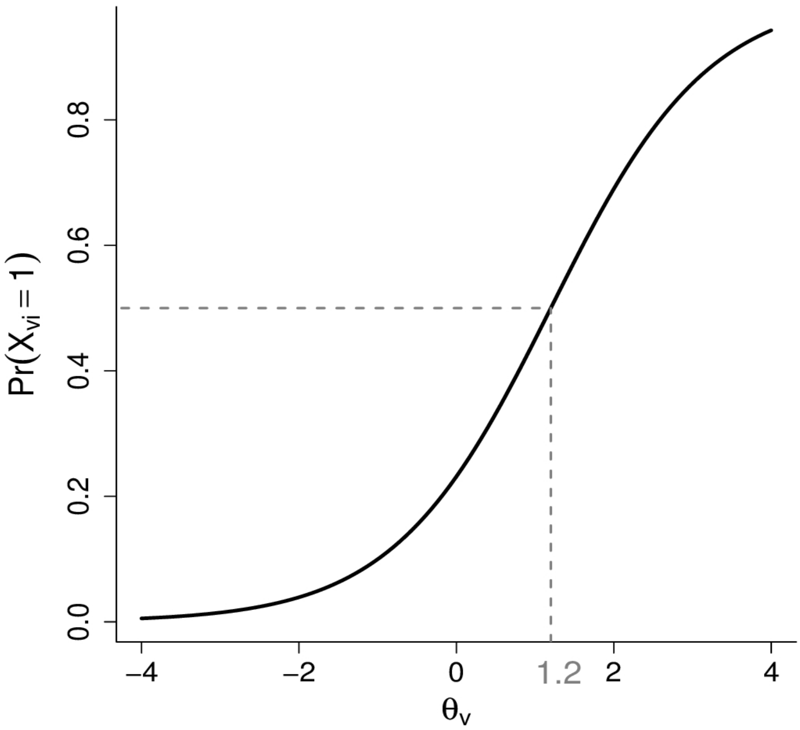

Figure 2.6: *The item characteristic curve (ICC) of the dichotomous Rasch model for a given item difficulty β_i=1.2.*

The ICC visualized above shows a sigmoid increase of the probability of correctly answering an item with difficulty β_i=1.2 for a range of person parameters θ_v. It is clear, that this function has to be sigmoid, as the lower bound (probability of solving is 0) and upper bound (probability is 1) are by definition restricted. The curve also shows that if both θ_v and β_i are equal, the probability of correctly answering the item is 0.5.

The Rasch model describes an ideal case, in which the most important assumptions of a questionnaire, which are necessary for it being reliable, are fulfilled. These are e.g. the unidimensionality of items, as described earlier. This means that all items mainly assess one specific latent trait of the person, which is tested, e.g. knowledge in a constrained topic. Mathematically, this is given by a high positive correlation between the items (i.e. a rather weak person will with a high probability answer similar items wrongly, whereas a rather strong person will with a high probability give the correct answers to similar items). Yet, another important characteristic of the Rasch model is that it follows the assumption of local independence of items, which means that the probability of correct answer for an item must only depend on that specific item and not on others. The Rasch model does also assume that the results are independent of the sample and that specific subgroups, which could be defined within a tested group do not differ in their answers. The latter assumption can be used to test the validity of the Rasch model for a specific dataset by using the Anderson Likelihood Ratio Test.

The Andersen likelihood ratio test

Anderson (1973) developed a test, with which one can test, whether the answers one got for a specific questionnaire do deviate from the (null) assumption of the dichotomous Rasch model being valid. The basis of this test is the likelihood, which is defined as the product of the probabilities for the measured results given some specific parameters.

First of all, the parameters of the Rasch model (θ_v and β_i) can be estimated for any given dataset using a maximum likelihood approach, as it was described before. This means that one can determine those parameters under the assumption of the Rasch model, which maximize the probability to obtain the data one got.

The crucial point for the Anderson Likelihood Ratio Test is the basic assumption of the Rasch model that subgroups are invariant. Anderson concluded that if one would calculate the likelihood for two arbitrarily chosen subgroups of a dataset, there should not be a strong difference between them, if the Rasch model was valid. Thus, this test is based on dividing the dataset into subsets, for which the optimal Rasch parameters are determined using a maximum likelihood approach. The resulting two likelihoods are multiplied by each other and divided by the likelihood for the whole dataset (thus, a likelihood ratio is calculated). The test characteristic T_{LR} is then given by:

$$T_{LR} = 2 \ln \frac{\prod_g L_c^{(g)}}{L_c^{(0)}}$$

With $L_C^{(g)}$ being the likelihood of subgroup g and $L_C^{(0)}$ being the overall likelihood of the dataset.

Anderson found that this test characteristic is χ^2-distributed. Thus, the χ^2-distribution can be used to assess, whether a given dataset deviates significantly from a Rasch model or not. If not (i.e. if $p > .05$), the questionnaire can be treated as following a Rasch model and thus be considered reliable.

Applying the Rasch model in R

To assess the reliability of a questionnaire in R using the approach provided by the Rasch model, the package “eRm” for R has been developed by Mair and Hatzinger (2007).

Once installed, the package can be loaded into a running instance of R by using the command `library(eRm)`.

It is necessary that the data that are going to be analyzed have a specific form, which is a matrix with the tested students given by the rows and their respective answers by the columns of this matrix (which can for any given dataset be achieved through the functionality of `as.matrix()`).

A maximum likelihood parameter estimation with regard to the dichotomous Rasch model can be performed via `m1 <- RM(data)`, with data being the answers of the students in matrix format, as described above. While now several analyses with this object can be done, I will only focus on testing the validity of the Rasch model for the dataset `data` using the Anderson Likelihood Ratio Test, which is performed by `LRtest(m1)`.

This test returns an LR-value (which is equivalent to T_{LR} described above), the degrees of freedom being used for comparing it with the χ^2-distribution and the resulting p-value. If the latter is larger than 0.05, there is no significant deviation from the Rasch model and thus the questionnaire can be considered as being reliable. Note that using standard settings (which is usually sufficient), the dataset is divided at the median sum of correct answers, i.e. all tested students, the sum of correct answers of which lies above the median value for the whole sample, are one group, whereas all students, whose answers lie below the median, form the second group.

Chapter III Out-of-school learning in the botanical garden: Guided or self-determined learning at workstations?[1]

1. Introduction

1.1 Out-of-school learning settings reveal positive cognitive outcomes

„Field trips to museums, zoos and science centers or the natural environment could deepen students' understanding of subjects usually taught in the classroom" (Sturm & Bogner, 2010, p. 14). The named institutions as well as botanical gardens meet all demands of out-of-school learning settings. For example, the demonstration of living or "dried" animals/organisms could transport more information and could change students' beliefs and affective reactions, like the fear of snakes (Bitgood, 1989). Compared to classrooms, education of global environmental sciences at out-of school learning settings is possible in a more visual, visceral and trans-disciplinary way (Storksdieck, 2006). Teachers often make use of field trips to such settings to complement and supplement their instructions (Ackermann, 1998), as well as to form class cohesion and to increase the students' motivation (Storksdieck, 2006). Hence, in recent years many studies, especially in science education, focused on this topic. Researchers have mainly been interested in the comparison between classroom-based teaching and different out-of-school learning settings. Results of these studies showed a cognitive benefit of the out-of-school settings at museums (Sturm & Bogner, 2010), laboratories (Scharfenberg et al., 2007) and science centers (Dairianathan & Subramaniam, 2011). Yet, for a salt mine, Meissner and Bogner (2011) measured cognitive levels, which were comparable to those achieved in classrooms. Still, in all of these interventions students showed a significant increase in knowledge about the particular topic at the respective out-of-school learning setting.

1.2 Botanical gardens as informal learning environments

Nowadays botanical gardens in Germany are not only museums for plants under the motto "don't touch". For instance, in some German cities, like Frankfurt am Main, Heidelberg, Ulm

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and Mainz, so-called “green schools” or “green classrooms” add an educational and sustainable component for all age groups of garden visitors, but especially for students in schools and universities. In the surroundings of a few, especially large, cities, several landscape forms, like for example meadows and forests, can only be found in botanical gardens. Consequently, botanical gardens are today not only responsible for the rearing, cultivation and research of plants, but also for the comprehensive communication of knowledge in a didactically appropriate manner. Trips to botanical gardens allow a teacher to be comparably flexible regarding the topic and offer opportunities to meet and involve experts. Additionally, botanical gardens are not necessarily learning environments focused on botany or even biology. Besides topics like adaptation or plant-animal-interactions, students can there potentially also learn about for example geography or natural or human history. Hence, an important current task of botanical gardens, namely environmental education and education for sustainable development (Willison, 2006), can effectively be addressed.

Botanical gardens are informal learning environments (Sellmann & Bogner, 2013), as they fulfill the four preconditions summarized by Storksdieck (2006): 1. Media are present to visualize the botanical and/or global context. 2. Botanical gardens have to be visited by the students. 3. Students get the chance for primary encounters with plants and animals and gain knowledge about species and 4. they can learn about ecological and environmental issues (Killermann et al., 2008). Additionally, out of school lessons tend to be more open and socially interactive (Hofstein, Nahum & Shore , 2001). The atmosphere is often more relaxed (O'Brien & Murray, 2007), bearing no school time pressure in concert with a non-evaluative nature. All of these advantages can potentially foster the learning of students. Sellmann and Bogner (2013) found significantly higher knowledge scores for 10th graders following an instruction in a botanical garden for the topic of climate change. They also measured the students' attitudes towards utilization and preservation of nature, according to the Two Major Environmental Value model of Bogner and Wiseman (2006). Also, Drissner, Haase and Hille (2010) investigated effects of a short-term education program regarding small animals in the “green classroom”. Both analysis revealed positive effects of the interventions in botanical gardens on the utilization, but not on preservation values. Furthermore, the intrinsic motivation of the involved students was higher in comparison to control groups (Drissner et al., 2010). Thus, education programs in botanical gardens could influence cognitive, affective and motivational attitudes positively.

1.3 Intrinsic motivation inventory (IMI)

In this study we investigate, adjacent to the learning outcome, whether students are intrinsically motivated for the topic *plants and water* in the setting of a botanical garden. In this context we make use of the intrinsic motivation inventory (IMI), established by Deci and Ryan in 1985. The IMI is based on self-determination theory, which suggests that people are intrinsically motivated when doing something inherently interesting or enjoyable (Ryan & Deci, 2000). In contrast, extrinsic motivation results in low-quality learning, because the act itself leads to an extrinsic, separable outcome, like a grade for instance. However, intrinsic motivation results in high-quality learning and creativity (Ryan & Deci, 2000), which is desirable in education research.

1.4 Student-centered vs. teacher-centered approaches

Few studies in the last decade dealt with the effects of student-centered against teacher-centered methods at out-of-school learning settings, like laboratories (Scharfenberg et al., 2007; Abrahams & Millar, 2008; reviewed by Hofstein & Lunetta, 1982, 2004), natural history museums (Wilde, Urhahne & Klautke, 2003) or zoos (Randler et al., 2011). Scharfenberg et al. (2007) detected a higher short-term learning outcome for the so-called *hands-on* group. Additionally, Randler et al. (2011) found best scores for the learner-centered environment six weeks after the zoo visit. However, Abrahams and Millar (2008) as well as Wilde et al. (2003) did not find significant differences between several compared learning methods over longer time-scales. Furthermore, there are many studies, which compare (constructivist) student-centered to (instructional) teacher-centered approaches within classrooms (e.g. Gerstner & Bogner, 2010; Heyne & Bogner, 2012; Randler & Bogner, 2006; Sturm & Bogner, 2008). However, the results of these studies were contradicting. Also, neither of them was focused on botanical gardens or on a botanical topic. Our intention was to bridge this gap and to investigate the learning outcome as well as motivational differences of a teacher-centered compared to a student-centered approach at this particular informal environment.

The most often used educational methods in botanical gardens worldwide are guided tours, talks and lectures as teacher-centered methods, followed by student-centered interventions, like workshops or training courses (Kneebone, 2007). Approximately 20% of the botanical gardens evaluate their educational programs on the regular basis, with a focus on the effectiveness of the programs. Yet, they do so mainly by observations. Hence, the aim of our study is to investigate, whether often conducted student-centered workstations are more successful in teaching at a botanical garden (with regard to motivation and cognition) than teacher-centered workstations (similar to guided tours). Our student-centered workstations were designed on the basis of a constructivist approach. For the guided approach (instructivist) we used the same workstations, but involved a teacher instructing the students successively (see methods section). With this classification we follow the work by Heyne and Bogner (2012), although they called the guided approach *student-centered guided* or *guided learning at workstations*. The authors additionally made use of a third group, which was teacher-centered *sensu stricto*. In our study we omit this third group.

The student-centered workstations we developed adhere to the requirements of the three innate needs of the self-determination theory (SDT, see above), which should foster learning and retention (Randler et al., 2011): competence (Harter, 1978; White, 1963), relatedness (Baumeister & Leary, 1995) and autonomy (deCharms, 1968; Deci, 1975). In our approach, a student in a student-centered group may act depending on its competence, while working in a small group, and simultaneously interact with around two to four group members. Another attribute of the student-centered learning method is that the students can freely decide about the order, in which they work on the stations, and determine the working time needed for each station. Thus the students are comparably autonomous – they can conduct all trials by themselves and may decide, whether they want to gain knowledge via texts, images or originals (plants). All these attributes stand in contrast to the teacher-centered workstations we developed, where the students had to follow the teacher's order and speed. Furthermore, the teacher showed trials and images during his talk for a bigger group of 13 to 18 students. The teacher-centered workstations do not meet the requirements of the self-determination theory and should lead to lower motivational values and consequently to lower cognitive achievement. In general, we hypothesize:

1. *Students, who participate in the student-centered workstation program, show higher motivation than those attending the teacher-centered program.*

2. *The student-centered workstations lead to higher cognitive outcome than the teacher-centered workstations at the out-of-school learning setting botanical garden.*

1.5 Gender effects at out-of-school learning settings

Recently, some studies support the hypothesis that females prefer learning about botany, when compared to males (Fančovičová & Prokop, 2011; Hong, Shim & Chang, 1998; Prokop, Prokop & Tunnicliffe, 2007). Following from this we expect females to achieve higher cognitive scores than males, caused by a higher emotional preference of females for plants. This phenomenon is usually traced back to the evolutionary history of humans. Once, females predominantly were gatherers (Kaplan, 1996), whereas males went hunting. Thus, females are expected to be more attracted to plants. To our knowledge, with respect to the teaching method, neither males nor females showed any preference for student or teacher-centered approaches in previous studies (Meissner & Bogner, 2011; Randler & Bogner, 2006). Based on these results and the evolutionary psychology hypothesis we develop a third hypothesis for our study:

3. *Females taking part in the intervention at the botanical garden show a higher learning outcome in both intervention groups because they are more motivated than males.*

2. METHODOLOGY

2.1 Student sample

In summer of 2011 altogether 404 eighth grade students with an average age of 14.1 years from 14 Bavarian middle schools, so called “Realschule” (RS) and “Mittelschule” (MS), took part in this study. 229 of them were males and 175 were females. These students complete their school career at 10th grade and achieve a mid-level graduation. However, there are differences between the two school types. At the “Mittelschule” physics, chemistry and biology are covered in one subject, at the “Realschule” every field is a subject for itself. However, the contents are generally similar from the fifth to the eighth grade. Except for 57 individuals, all of the students visited the botanical garden of the University of Würzburg for one day. Those who did not formed the control group (C). The participating students were divided into a teacher-centered group (T, n=169) and a student-centered group (S, n=178), with respect to the intervention type. Always one class was assigned to one of each groups. This assignment of classes to both treatments was randomly drawn.

2.2 Study design

Within our quasi-experimental approach, we followed a before-after/control-impact design (Randler & Bogner, 2009). A control group is necessary to test for potential external effects between the tests (Lienert & Raatz, 1998). To measure already existing knowledge about the topic, one week prior to the garden visit, all students had to answer a multiple-choice-test with 14 questions (two questions for each topic/workstation) in school, the pretest (for example questions see Fig. 3.1). Immediately following the respective treatment, students of both teaching methods had to complete the same test (with a random sequence of questions) to account for the cognitive outcome (posttest). Long-term learning (retention) was assessed six weeks after the garden visit in school. The control group only got the questionnaires for two measurements, pretest and retention, without any instruction (Fig. 3.2).

For our analysis, we concentrate on the motivation and increase in knowledge of the students. This choice is due to our goal of maximizing learning success of students with respect to their current curriculum. Therefore it is necessary to either assess their knowledge or comprehension of processes and relations. The latter, however, is difficult to assess, but might offer an interesting extension of this study. Yet, to supplement the findings based on knowledge scores, we also assess the intrinsic motivation of students (see above). The combination of both measures allows for a proper comparison between the tested treatments.

One of the function of the root hairs is …

- ☐ *… to release sugar.*
- ☐ *… to assimilate sugar.*
- ☐ *… to enlarge the surface area.* *(correct answer)*
- ☐ *… to reduce the surface area.*

Where does *Aloe vera* accumulate water?

- ☐ *In the flower.*
- ☐ *In the stem.*
- ☐ *In the leafs.* *(correct answer)*
- ☐ *In the root.*

How are the structures of a leaf called, which allow the plant to yield dioxygen and steam?

- ☐ *Leaf pores.*
- ☐ *Stomata.* *(correct answer)*
- ☐ *Closing splits.*
- ☐ *Steam cut.*

Figure 3.1: *A translated selection of exemplary questions of the knowledge questionnaire. Correct answers were originally not indicated.*

Usually, Cronbach's α is calculated to assess the reliability of questionnaires (Drissner et al., 2010; Gerstner & Bogner, 2010; Scharfenberg et al., 2007). For reasons of completeness, we have thus also calculated this measure for the knowledge questionnaire results. We obtained values for Cronbach's α of 0.59 (pretest), 0.61 (post-test) and 0.65 (retention). According to Lienert and Raatz (1998), values between 0.5 and 0.7 allow for the differentiation of groups. However, this measure shows severe weaknesses (especially as it provides no information about internal test structure, i.e. unidimensionality; for details and additional literature see Sijtsma, 2009). Therefore we extended the analysis of the quality of our questionnaire by applying a Rasch model using the R-package “eRm” (version 0.15; Mair & Hatzinger, 2007). We performed Andersen's likelihood ratio test (Andersen, 1973) and got no significant deviation from the assumption of a Rasch model being valid ($X^2 = 20.6$, df $= 13$, $p > .05$). Thus, the prerequisites of a Rasch model are met. This means that the items are to a satisfying degree powerful, unidimensional and not strongly correlated (Koller, Alexandrowicz & Hatzinger, 2012). Consequently, we can assume our questionnaire to provide reliable results, which allow inference of the latent cognitive traits of the students. This also justifies working with the sums of knowledge scores for each student (see below).

Every participant of both groups received a workbook to save individual results. These workbooks were adapted to the teaching method: Whereas for the teacher-centered approach the books contained only questions regarding the stations, in the student-centered approach these questions were supplemented by working instructions. The program itself consisted of two lessons, with an overall duration of approximately 90 minutes. Following a short teacher-centered introduction concerning the plants' needs for water (approx. 30 min.), the teacher (which was the same for all groups) also introduced the workbook, which was relevant for the success of the intervention (Sturm & Bogner, 2008). The teacher in our study was a preservice teacher with biology as major subject, already holding a first state examination.

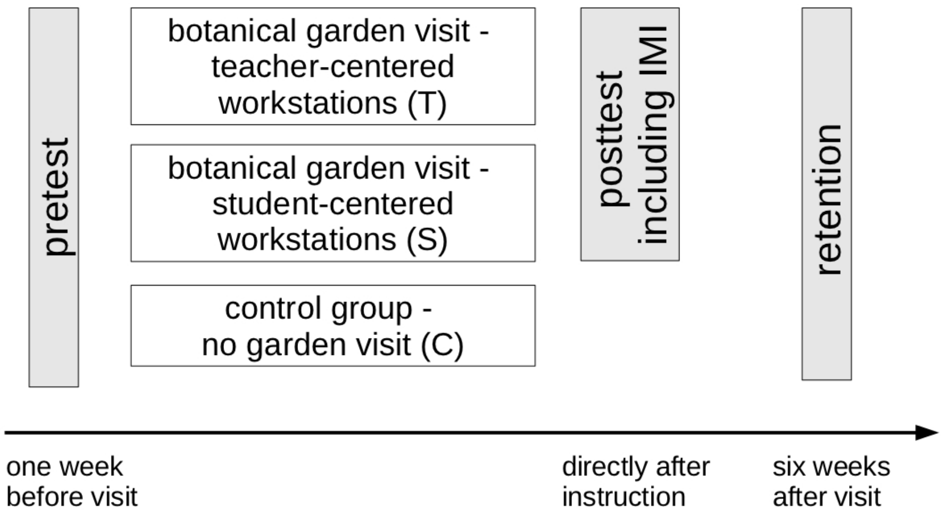

Figure 3.2: *Schematic representation of the study design. Performed tests are shown in gray, the arrow below denotes progression of time.*

In case of the student-centered workstations, students were self-dependent and able to work free-choice according to the definition of *learning at workstations* (Gerstner & Bogner, 2010). They worked together in small groups of three to five individuals and decided, in which sequence they attended the six obligatory workstations. In combining the experimental materials, pictures and all the additional information at the workstations the students were able to answer the questions in the workbooks. One optional workstation was designed for fast and motivated learners. All seven workstations were independent of each other and covered the following topics:

1) water absorption through root hairs (example: *Lepidium sativum* L.),
2) water transport in vascular strands (example: *Apium graveolens* L.),
3) root pressure (example: *Clematis vitalba* L.),
4) transpiration (example: *Ocimum basilicum* L.),
5) succulence (example: *Aloe vera* BURM. F. in comparison to *Plantago major* L.),
6) adaptation to the habitat "pond" (example: *Nymphaea spec.*),
7) optional: adaptation of *Tillandsia usneoides* L.

To avoid overcrowding of students at the stations, we placed several copies of instruction sheets and material at each station. After acting at the workstations the students compared their results to an answer booklet provided by the teacher after finishing work at all stations. Of course, the teacher answered additional questions.

In contrast to the procedure described above, for the teacher-centered approach one teacher led a group of approximately 15 students along a route covering the six obligatory workstations in the order of the listing above. At every workstation the teacher demonstrated trials, discussed the results and visualized the contents using illustrations, while the students were answering the questions in the workbooks to record the results.

2.3 Intrinsic motivation inventory

Immediately after the treatment twenty-three items of the intrinsic motivation inventory (IMI; Deci & Ryan, 1985, 1992) were delivered to the students, in combination with the knowledge questionnaire. Four sub-scales were integrated – tension, student's interest, perceived competence and perceived effort – each with a selection of five to seven questions. In accordance to Schaal (2006) we translated the items. The students had to choose between four categories for each statement: "not at all true", "somewhat true", "already true", "very true". Originally the IMI was intended for adults, but in the last years it has also been applied for fifth or ninth graders (e.g. Gerstner & Bogner, 2010; Sturm & Bogner, 2008).

2.4 Statistics

We used generalized linear mixed models (GLMM; Bolker et al., 2009), since the data we collected were nested and this method additionally allowed us to evaluate different hypotheses simultaneously. We used the sums of knowledge scores for analysis and thus assumed a Poisson error distribution, as we gathered count data (Crawley, 2007). Furthermore, as we have potentially influencing random factors, which are hierarchical, we defined student's identity nested in class nested in school place as random effects of the model. Treatment, test time (pre-, post-, retention-test), gender and school type were specified as fixed effects. To calculate the GLMMs we used the R language for statistical computing (version 2.15.0; R Core Development Team, 2012). To implement the models we used the “glmer” function from package “lme4” (version 0.999999). We initially implemented a full model with all possible interactions and performed model selection by means of the Akaike information criterion (AIC; e.g. Vatka, Orell & Rytkonen, 2011). We also provide p-values based on Wald tests for the single explanatory factors of the resulting model. However, these values should not be overestimated, since model selection was still based on AIC comparisons – thus, the Wald tests were rather performed to estimate the influence of individual factors. Additionally, their calculation remains imprecise (Zuur et al., 2009). Due to the fact that the control group was only tested before and six weeks after the study time, we formulated two models. One model contained the two treatments (T, S) for all three times of measurement and another model additionally included the control group, but only for pretest and retention. For each of the four IMI sub-scales we constructed one GLMM including all questions of the particular sub-scale. Interaction-plots of the respective interaction terms from the resulting models were created for reasons of clarity.

3. Results

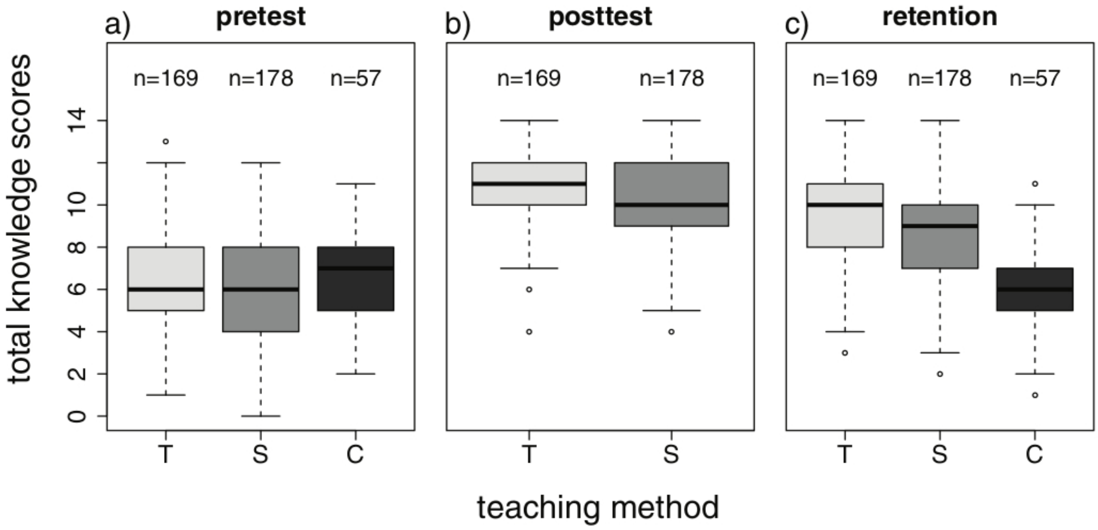

Figure 3.3: *Total knowledge scores of the two teaching methods and the control group("T" = teacher-centered workstations,"S" = student-centered workstations,"C" = control group) for three measurements (a, b, and c). For the control group no data were collected at the time of the posttest.*

The students' knowledge about the topic *plants and water* increased significantly for both treatment groups following the instruction (Table 3.1). Their median knowledge score increased about five points for the teacher-centered workstation group (T) and four points for the student-centered workstation group (S; Fig. 3.3a, b). Only few students (17%) gained enough knowledge during the instruction to get a perfect score. Six weeks later knowledge of the students of both treatments decreased (Table 3.1), with a magnitude of approximately two points (Fig. 3.3b, c). In the pretest the control group (C) had shown slightly higher knowledge (Fig. 3.3a) compared to the other groups. Interactions were hence significant between the performed test (retention) and the treatment (control vs. teacher-centered, Wald test: $z = 4.477$, $p < .001$; control vs. student-centered, Wald test: $z = 4.560$, $p < .001$).

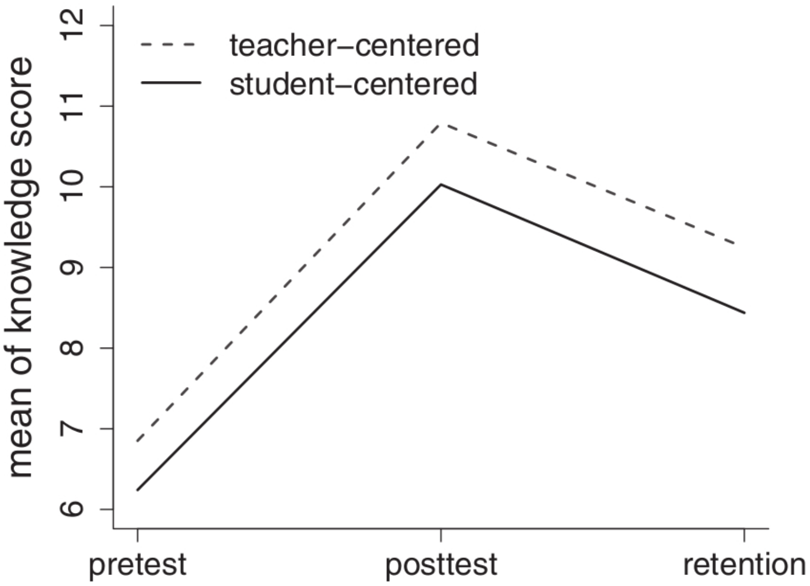

Figure 3.4: *Interaction between measuring time and treatment.*

The interaction-plot in Figure 3.4 shows that those students following the teacher-centered approach knew approximately one point more from the beginning until the end of the study in comparison to the students participating in the student-centered approach. However, both curves increase and decrease with a similar slope, thus showing that there was no effect of the treatment on learning outcome (note that this slight difference is not apparent in Fig. 3.3, as there only median values are plotted).

The final model contains an interaction between pretest and females (Table 3.1), indicating that female students performed slightly worse than males in the pretest, but not in the posttest (see also Fig. 3.5). The cognitive outcome of the females thus seems higher. Their scores increased by a value of approximately four following the garden visit, whereas the males' scores increased by three. Further, the females forgot less than the males from posttest to retention, but this interaction was fairly weak (Table 3.1).

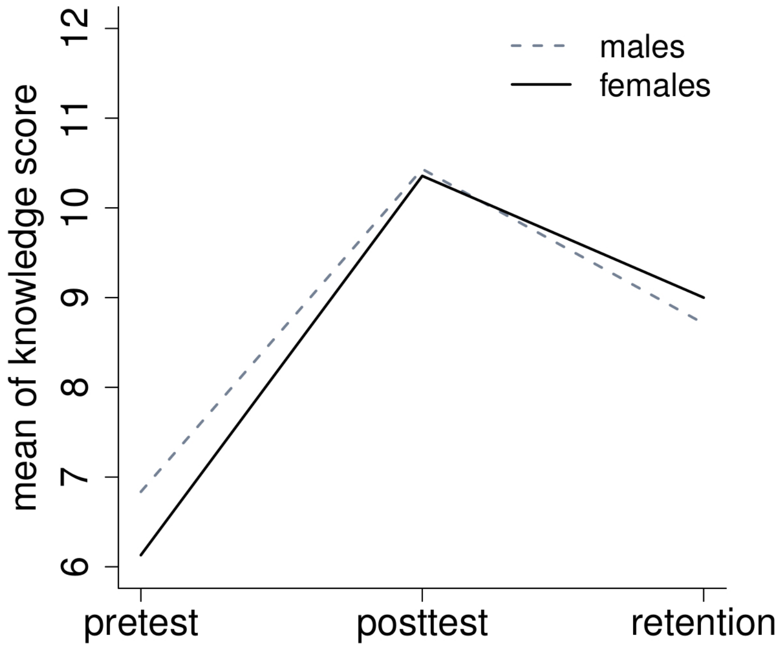

Figure 3.5: *Interaction between measuring time and gender.*

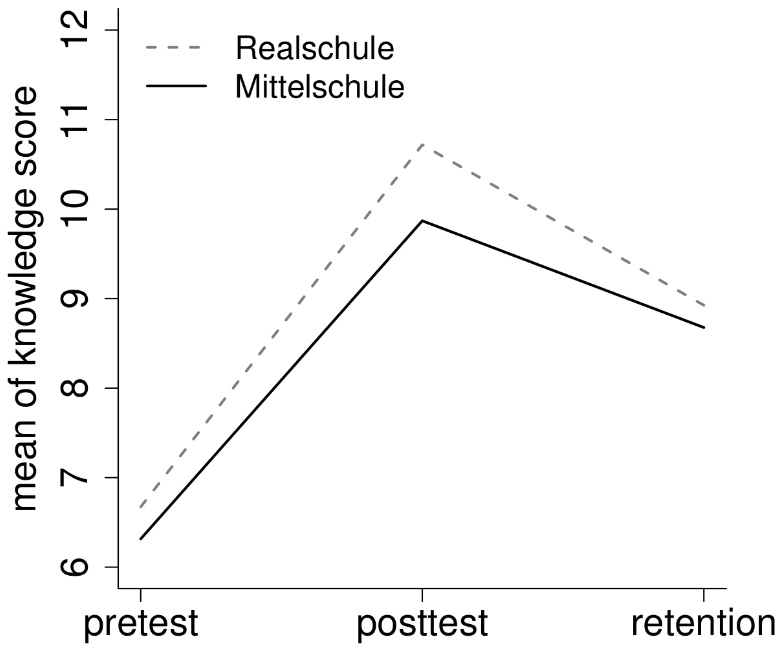

Figure 3.6: *Interaction between measuring time and school type.*

Furthermore, students from the “Realschule” achieved significantly higher knowledge scores than students from the “Mittelschule”. As Figure 3.6 shows, the school types did not differ much between pretest and retention. However, the learning outcome after the instruction was higher for the students of the “Realschule” (one score). From the very beginning of this study the RS-students showed slightly higher scores for the teacher-centered approach, as can be seen in the negative regression estimate (-0.16). However, we detected no strong interaction between treatment and MS-students.

Table 3.1: *Results of a general linear mixed model with test time, gender, treatment and school type as fixed effects and code, class and school place as random effects. Shown is the final model resulting from AIC selection (Vatka et al., 2011; Zuur et al., 2009). The values for the different fixed effects categories are referenced to those not written in the table. z-and p-values result from Wald tests of the single explanatory variables. * p < .05. *** p < .001.*

Fixed effect		**Regression estimate**	***z*-value**	***p***
Category	Value			
Time	Pretest	-0.423	-12.18	< .001 ***
	Retention	-0.180	-5.57	< .001 ***
Treatment	Student-Centered	0.007	0.11	> .1
Gender	Females	0.004	0.12	> .1
School type	Realschule	0.142	2.46	< .05 *
Time x Gender	Pretest x Female	-0.102	-1.86	< .1 .
	Retention x Female	0.049	0.80	> .1
Treatment x School type	Student-Centered x Realschule	-0.157	-1.88	< .1 .

The interest of the students was high with a mean of three at a scale from zero to four (no interest to high interest), even though the perceived effort was also high with a mean of three for both treatments (Fig. 3.7). However, the students apparently felt low tension and rated themselves competent for topic and activities. The students' intrinsic motivation was also indifferent within the two groups (T, S), thus being similar to the measured cognitive knowledge about *plants and water*. Between the two groups the means as well as the quartiles and the maximum and minimum values were almost equal. Hence, model selection for GLMMs for all sub-scales resulted in null models with no significant effects remaining.

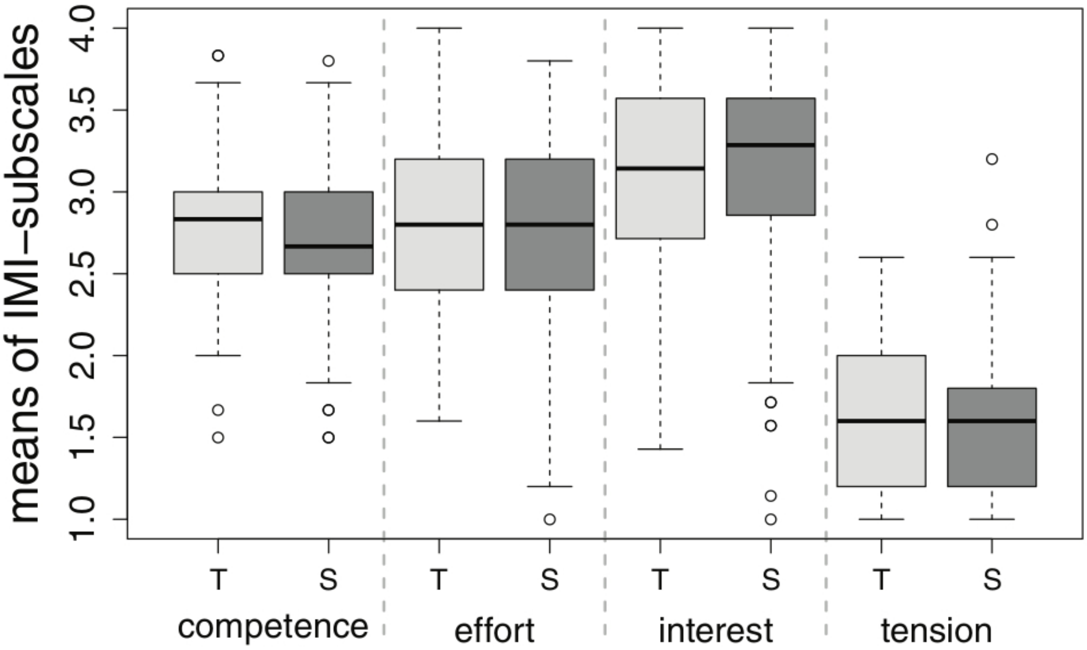

***Figure 3.7**: Comparison of the means of the Intrinsic Motivation Inventory sub-scales (“competence” = perceived competence, “effort” = perceived effort) regarding to the two teaching approaches (“T” = teacher-centered workstations, “S” = student-centered workstations).*

4. Discussion

4.1 Teacher- vs. student-centered workstations

Concerning our first hypothesis the students showed no higher intrinsically motivated preference for the student-centered approach. In fact, their motivation was equally high for both treatments. This result stands in contrast to Sturm and Bogner (2008). The authors found a higher overall motivation for their student-centered group regarding interest and well-being (see also Schaal & Bogner, 2005).

Generally, the IMI scores of our study are comparable to the scores of other studies at out-of-school settings (Meissner & Bogner, 2011; Sturm & Bogner, 2010), even though participants there were confronted with five optional categories. We assumed the signal to be more clear if the students can only choose between four categories. However, they nevertheless tended to favor the two middle scores (except for the interest sub-scale, see Fig. 3.7).

The second hypothesis we had formulated in the introduction cannot be confirmed by our results. The student-centered approach was as good for the cognitive outcome of the participants as the teacher-centered one. Both treatments resulted in a higher knowledge score for a short and a longer time frame after the garden visit. Our results go in concert with the study of Wilde et al. (2003) and additional research focused on laboratories (reviewed in Hofstein & Lunetta, 1982, 2004; Abrahams & Millar, 2008), as these could also not reveal any significant differences between teacher- and student-centered approaches. However, Randler et al. (2011) found that the teacher-centered method was more effective with respect to the short-term learning outcome, although six weeks later the knowledge of the student-centered group was higher.

The fact that we could not detect higher intrinsic motivation for student-centered workstations may act as an explanation for a missing difference in cognitive outcome. As Ryan and Deci (2000) have clearly stated, only intrinsic motivation provides the means for the successful learning of students. Generally, the comparably high motivation we measured might very well be a consequence of the diverse and stimulating learning environment, which can be found in a botanical garden. This supports previous results on the positive effects of out-of-school settings on motivation and cognition (Storksdieck, 2006; Drissner et al., 2010).

Successful learning at student-centered workstations requires certain abilities of students regarding cooperative and self-determined behavior (Schaal & Bogner, 2005). However, nowadays in Germany most students rarely work under such conditions, although the German curriculum demands to facilitate such competences in school lessons. In everyday school life there is often no time and/or no material for such learning methods. Additionally, in the present study during the work at the stations the students were disturbed by gardeners and garden visitors. However, the teacher helped the students to keep their attention focused on the topic and the materials. The teacher in our study also spun a common thread through the teacher-centered workstations similar to a guided tour, which made the content logically easier to follow. The teacher showed the students how to solve the exercises and trials, too. They only had to concentrate on the content and on recording their results.

Thus, positive and negative effects of the two applied instructional approaches balanced each other, leading to an equal knowledge gain for short- and long-term learning outcome. As the long-term cognitive results of our study were not very high with an increase of approximately two scores for both treatments, we suppose that the topic was too difficult and the intrinsic motivation of the students was not high enough.

With regard to the school type, the RS-students in the teacher-centered group achieved higher knowledge scores in the pre- and posttest, as well as in the retention, than the MS-students (Fig. 3.6). The fact that these higher scores were also observed in the pretest, leads us to the conclusion that it was based on a randomly biased sample. Those RS-students with the best scores were by accident accumulated in the teacher-centered group. This result shows the need for the pretest to avoid drawing false conclusions.

4.2 Gender effects

Our third hypothesis was that females should show a higher cognitive outcome and intrinsic motivation than males for a botanical topic. Indeed, in our study, females' seemed to profit more than males from the whole program, independent of the instructional approach. Yet, they were inferior to the males during the pretest. Except for the latter observation our results support the work of Fančovičová and Prokop (2011), which found higher knowledge of the females about plants for all of the three tests. However, we can also support Fančovičová and Prokop (2010) study on attitudes. Similar to their conclusions, there are no differences in the motivational preference for a botanical topic between genders, based on our results regarding the IMI, although it stands in contrast to the evolutionary psychology hypothesis mentioned in the introduction. With respect to the treatment method we found no gender effects, which is in accordance to a series of studies (e.g. Meissner & Bogner, 2011; Randler & Bogner, 2006; Schaal & Bogner, 2005). In summary, there is no preference of either males or females for either the teacher- or student- centered approach.

4.3 Potential limitations and future prospects

It might be seen as a limitation that the two learning methods, we used – teacher-centered and student-centered workstations – do not differ greatly, i.e. do not drastically confront a constructivist with an instructivist approach. Yet, we are convinced that our design allows us to pinpoint the effects of an increased involvement of the teacher. By changing only this parameter, we can eliminate other potential influences.

However, a shortcoming of our study is that we do only measure direct knowledge increase. Although we expect knowledge scores in combination with intrinsic motivation to provide a good approximation of general learning success, results may differ, when deep understanding of processes or the transfer of knowledge would be measured. In this case, student-centered workstations might be of higher value. It will certainly be an interesting challenge to assess these factors in future studies.

As formulated in the introduction, field trips to botanical gardens as described in this paper might be able to induce affective and attitudinal changes of students towards plants. By using the intrinsic motivation inventory in combination with knowledge scores, we aimed to shed light on this process. However, as our study revealed equally high motivation for all students, we cannot draw any conclusions on affective or attitudinal changes, yet. More research will be necessary to fill this gap.

One very important factor for the success of a given intervention regards the competence and motivation of the teacher. In our study, teaching was conducted by a preservice teacher, who already had achieved the first state examination. However, in many botanical gardens for example horticulturists conduct learning programs (Kneebone, 2007). We would expect variability in motivation and competence to be higher among these guides than among educationally trained personnel. The influence of the teacher's profession is certainly an important research topic for future studies.

5. Conclusions

Botanical gardens are as suitable as out-of-school learning settings for students of the lower secondary school as museums or zoos. The measured interest and cognitive outcome are similar to other studies. One of the main advantages of out-of-school settings is the chance for haptic and visual perception of an often difficult and theoretical topic regarding plants. Botanical gardens thus have the best chance of all out-of-school learning settings to counteract *plant blindness* (Wandersee & Schussler, 1999, 2001). Yet, only few botanical gardens evaluate the effectiveness of conducted programs comprehensively or in an experimental way (Kneebone, 2007). With our study we work on filling this gap by comparing teacher- and student-centered workstations at this out-of-school learning setting. Our results show that constructivistic elements foster the learning outcome of students, regardless of the degree of the teacher's involvement. Thus, botanical gardens provide a perfect setting to supplement and complement school instructions. Nevertheless, future studies could focus on a comparison between our type of teacher-centered learning against traditional guided tours, consisting of teacher's speeches and only informal educational opportunities without constructivist elements. Another important task within this research field is a comparison between the botanical garden as an out-of-school learning setting and the classroom.

CHAPTER IV STUDENTS' ALTERNATIVE CONCEPTIONS ABOUT THE LOTUS EFFECT: TO CONFRONT OR TO IGNORE?[2]

1. INTRODUCTION

Concepts are *mental models* of certain events or structures in a learner's mind (Glynn & Duit, 1995). These models are relatively robust and often not conform to scientific perceptions (Treagust, 1988; Morrison & Lederman, 2003). They are influenced by many factors, such as the perceptions of parents, grand-parents, teachers, and more than ever by mass media. Unfortunately, mental models in scientific subjects are rarely based on experiences gathered through school experiments or first-hand experience with nature's phenomena. In every-day life of German students there often is a lack of such experiences, especially after primary school time. Consequently, to change the students' *alternative conceptions* (Murphy & Alexander, 2008) or *misconceptions* (Helm, 1980), will prove difficult for an educator, either in school or at an out-of-school learning setting. In this study we refer to the term *alternative conceptions*, defining common scientific beliefs, which have no basis on scientific facts.

First of all it is the educator's assignment to identify the students' conceptions regarding a specific topic. Further, he/she has to decide, whether to confront the students with their probably wrong conceptions in a lesson and which methodology should be used. And, last but not least, the educator has to decide, how to procure the scientific content and perception for the learners. Over three decades, researchers of psychology and natural sciences (Treagust & Duit, 2008) have asked the same question: What is the best way to achieve short and long-term conceptual change? A satisfying and comprehensive answer to this question has, however, not been found yet.

1.1 Conceptual Change Theory

The theory of conceptual change is a well investigated topic in learning and teaching research (Vosniadou, 2008). Posner et al. formulated four detailed *conditions of accommodation* (1982). An accommodation is in their view a radical form of conceptual change. This means that the learner must change and replace his/her concepts, if the old perceptions are not sufficient to understand and explain a new phenomenon. The four conditions for an effective

2 This chapter is in revision at the Journal of Biological Education as: Kubisch, F., & Heyne, T. Students' alternative conceptions about the lotus effect: To confront or to ignore?

conceptual change imply that firstly, a student gets discomforted with an old conception, a new conception has secondly to be logically entire, thirdly plausible and fourthly fertile (Posner et al., 1982; Franke & Bogner, 2011a). Limón (2001) claims that this is not a radical, but a slow continuous and gradual learning process, although there are “kinds of conceptual changes that happen spontaneously in the learner's development” (Vosniadou, Vamvakoussi & Skopeliti, 2008, p. 4). With regard to the concept of the earth’s shape, for instance, it is “not a simple belief (Chi, 2008), which had changed, but a radical conceptual change” (Vosniadou et al., 2008, p. 8). The learner tries to combine the scientific view – the earth is spherical – with his nonscientific perception – the earth is rectangular – which results in a mixed conception of a disk earth. These mixed conceptions are called *synthetic models* by Vosniadou et al. (2001). Hence, the process of conceptual change depends on many factors, like prior knowledge, missing knowledge (Chi, 2008) and the ability to form new structures (Vosniadou, 2003). The process could further be facilitated by the consideration of sociocultural (Hatano, 1994), motivational (Pintrich, Marx & Boyle, 1993) and affective aspects (Duit, Treagust & Widodo, 2008, p. 634).

Conceptual change is similar to the scientific method. Following the philosophy of Karl Popper, scientific progress can only be achieved through the falsification of hypotheses (Popper, 1959). As a consequence, given a scientist disproving a hypothesis, the scientist has to change his conceptions. The similarity of the scientific method sensu Popper to the process of conceptual change makes the research in this field with regard to scientific topics even more interesting.

In the present study we investigate the change in students' conceptions of the water-repellent lotus effect and, in this context, conceptions of the biochemical properties of water. The functioning of the lotus effect resulting in its water- and therefore also dirt-repellant characteristics is based on a rough leaf surface made up of wax crystals (Neinhuis & Barthlott, 1997). Yet, usually most people think of a rather smooth surface leading to this effect, which is a common misconception and makes it an appropriate issue to investigate. To our opinion, student’s conceptions on water-repellants are shaped by their confrontation with every-day life applications, such as water-repellent shower cubicles, cagoules, or Teflon-coated pans. Thus we decided to assess the value of the method of conceptual change regarding this topic, because alternative conceptions for it are assumingly widespread. Additionally it is in its botanical nature well fitting to the application in botanical gardens as out-of-school learning settings, which allowed us to enhance the field of conceptual change research into this direction. We consequently measured the students' learning achievement following a constructivist instruction integrating the students' conceptions of this scientific topic.

1.2 Conceptual change and instructional methods

In late science education studies, several instructional designs were tested, like pictures (Franke & Bogner, 2011a), refutation texts (Pöhnl & Bogner, 2013a, 2013b) or conceptual change texts (Durmuş & Bayraktar, 2010), concept maps (Akbaş & Genctürk, 2011) or computer animations (Çalik et al., 2010). The majority of researchers used two to three different kinds of instructional methods. They intended to produce a cognitive conflict in the learners' minds as one step of conceptual change (Piaget, 1974). Posner et al. (1982) specify this step as "dissatisfaction with existing concepts". Therefore, the activation and *metaconceptual awareness* of prior knowledge is essential for restructuring existing knowledge (Vosniadou et al., 2001; Pöhnl & Bogner, 2013b). The learner should realize during this phase that he needs to *reorganize* and change his ideas and views (Limón, 2001). The first challenge for the educator is that the student needs to become aware of the conflict at all. If this requirement is fulfilled, the learner should be willing to restructure his prior knowledge. Depending on the topic's relevance, the student's interest (Mason et al., 2008), and the individual motivation (Pintrich et al., 1993), a successful conceptual change is possible. Consequently, confronting the students with their alternative conceptions is the main phase in the process of conceptual change. Before conducting a lesson or an experiment, the educator has to carefully consider the appropriate instructional method to use and has to develop a corresponding program.

In science education the use of computer simulations or software fosters the conceptual change process (Li, Law & Lui, 2006; Linn, 2008; Hobson, Trundle & Sackes, 2010). Jonassen (2008) recommends computer based concept mapping for achieving conceptual change, especially for chemistry. Generally, concept mapping supports the acquisition of new knowledge (Horton, McConney, Gallo & Woods, 1993). If creation and structuring of the maps is aided by computer software, the students are more flexible in reorganizing their maps and also more motivated (Jonassen, 2008). Regarding biological concepts, like plant respiration, photosynthesis and genetics, Tekkaya (2003), Yenilmez and Tekkaya (2006), Yilmaz, Tekkaya and Sungur (2011) and Pöhnl and Bogner (2013a, 2013b) demonstrated the effectiveness of so-called refutation texts or conceptual change texts for secondary school students. These texts should be designed in accordance to the conditions of Posner et al. (1982) for a successful change of the students' concepts (Hynd, 2001, 2003). However, these instructional designs require certain technical skills from the students, as well as good text comprehension abilities and the capability for cross-linked thinking. Hence, for younger and cognitive weaker students, analogy and models (Wichaidit, Wongyounoi, Dechsri & Chaivisuthangkura, 2011), games (Ketamo & Kiili, 2010), pictures or computer animations, seem to be a better choice. Another factor to consider when choosing an instructional method is the interaction between the teacher and the students, or between the students themselves, while being confronted with alternative conceptions and getting presented the scientific views. Here we follow the assumption that conceptual change is not only an internal and individual cognitive process, but the product of interactions and interrelations between the involved agents (Vosniadou et al., 2008). We assume that these interactions foster the effect of different instructional designs.

1.3 Botanical gardens as out-of-school learning settings

Recently, there has been an increase in research on education in botanical gardens (Tunnicliffe, 2001; Drissner et al., 2010; Drissner, Haase, Wittig & Hille, 2014; Sellmann & Bogner, 2013). However, we are not aware of studies focusing on conceptual change in botanical gardens. Botanical gardens as out-of-school-settings can facilitate the conceptual change process, because the students get primary encounters with nature (Killermann et al., 2008) and lessons at this place have the potential to be more open and socially interactive than in classrooms (Hofstein et al., 2001). We would thus expect that botanical gardens are appropriate to increase the students' motivation (see also Drissner et al., 2014) and their willingness to change prior knowledge. Additionally, these out-of-school learning settings are well suited to improve the students' perception of the relevance of several scientific topics, like sustainability, for their daily life. It might thus be that the location as well as alternative teachers positively affect the students' ambition. Wiegand, Kubisch and Heyne (2013) could show that during an instruction in a botanical garden, intrinsic motivation of students was generally high. However, there is no guarantee for a successful conceptual change at such out-of-school learning settings. It might for example be that the students feel intimidated by the university's environment and a teacher being an expert for this topic. Consequently, they are afraid to do or say something wrong, which might lead to a decrease in their motivation and attention and thus to a lower probability of conceptual change (Limón, 2001).

1.4 Overview of the study

The aim of the present study was to find out, whether a conceptual change process can be fostered by confronting students with their alternative conceptions at an informal out-of-school learning setting, like the botanical garden. We therefore investigated short- and long-term learning of students about bionics (at the example of the lotus effect). Some of the students (group AC, see below for details) were confronted with their own conceptions, others not (group NAC). We tried not to overstrain the mid-level eighth grade students' by confronting them with e.g. texts with high densities of information and insufficient explanation, and thus used pictures, models and also discussions with the teacher, similar to Franke and Bogner (2011a). Here, one group of students was confronted with the three most frequently given alternative conceptions (assessed through an open questionnaire; the resulting wrong answers can be seen in the Appendix 5), shown by pictures, which were additionally explained by the teacher. The other instruction group only saw illustrations of the correct scientific view. Secondly, we fostered the changing process through the help of the interaction between the students during an experimental phase for both groups. With regard to the theory of Posner et al. (1982, see above), for a successful changing in concepts, we hypothesized that *learning achievement is higher for the group, which was confronted with their alternative conceptions in contrast to students which were not.*

2. Methodology

2.1 Student sample

We conducted this study with altogether 317 eighth grade students in summer of 2011. 190 of them were males and 127 were females. Students with a median age of 14 years from 15 Bavarian mid-level schools, so called “Realschule” (RS) and “Mittelschule” (MS), took part in this study. These students complete their school career at 10th grade and achieve a mid-level graduation. However, there are differences between the two school types. At the “Mittelschule” physics, chemistry and biology are covered in one subject; at the “Realschule” every field is a distinct subject. However, the contents are generally similar from the fifth to the eighth grade. Except for 57 individuals, all of the students visited the botanical garden of the University of Würzburg for one day. Those who did not formed the control group (C). The participating students were divided into one group confronted with alternative conceptions (AC, *n*=128) and a second group, which was not confronted (NAC, *n*=132).

Classes were randomly assigned to either of the two treatments as a whole.

2.2 Teaching unit on bionics with a focus on the lotus effect

At first each class was presented a short teacher-centered introduction concerning the plants' needs for water (approx. 30 min.), outdoors in the botanical garden. Then we split the class and worked in course rooms with 14 to 18 students and followed the constructivist teaching sequence of Driver (1989), which comprises 1. orientation, 2. elicitation of ideas, 3. restructuring of ideas, 4. application of ideas and 5. review change in ideas. For the alternative conception confronted group we used pictures in a presentation as well as a discussion between teacher and students to achieve the first step of the conceptual change process - the confrontation and thus dissatisfaction of the students with their own alternative conceptions, which we collected many weeks before. Meanwhile, and with the same instructional design aided by plant specimens, computer simulations as well as analogies and models were used to generate a logically and scientifically correct concept in the students' minds. This step was also done with the second instructional group (the NAC students; see Table 4.1). To deepen the understanding of scientific concepts in a next step the students conducted experiments, corresponding and interacting with their respective neighbors, on water-repellent plants. For the plausibility and fertility of the new concepts we discussed the biological role of the lotus effect and technical inventions regarding water-repellent properties, using the results of the students' experiments, and additional pictures. Every participant received a workbook (see Appendix 4) for the experimental phase to know what he / she was expected to do with the materials, and to record their results. The program itself consisted of two lessons, with an overall duration of approximately 120 minutes. The teacher, beforehand unknown to the students, was the same for all groups, to assure that only one experimental factor was changed.

Table 4.1: *Time schedule of the instruction during the botanical garden visit for the different groups.*

Teaching unit steps	Alternative conceptions confronted group (AC)	Non-alternative conceptions confronted group (NAC)	Control group
30 min	Introductory discussion with confrontation with students' alternative conceptions	Introductory discussion without confrontation with students' alternative conceptions	-
60 min	Experimental phase	Experimental phase	-
30 min	Discussion of results and review of the changed ideas	Discussion of results and review of the changed ideas	-

2.3 Study design

To assess the students' prior knowledge and pre-existing concepts about bionics and the lotus effect, a teacher visited every school class (with the exception of the control group) approximately 10 weeks before the students' visit of the botanical garden. During the visit the teacher gave the students 12 open knowledge questions, similar to the approaches of Franke and Bogner (2011a, 2011b) and Duncan and Reiser (2007). The students were given 40 minutes to fill out the questionnaire. After that we analyzed the students' answers and created from these a multiple-choice questionnaire with 10 new questions. Four answers were given, one of which presented the correct scientific view and three false answers were made up of the most frequent conceptions of the students (see Appendix 5).

One week before the garden visit all students had to answer this multiple-choice test in school - the pretest. Immediately following the respective treatment, students of both instructional methods had to complete the same test (with a randomized sequence of questions and answers) to assess the cognitive achievement (posttest). The long-term learning (retention) was assessed six weeks after the garden visit in school (Fig. 4.1). For every test we changed the order of the four possible multiple-choice answers and of the single questions, respectively, to avoid any bias. The control group only got the questionnaires for pretest and retention without any instruction. With this quasi-experimental approach we follow a before-after/control-impact design (Randler & Bogner, 2009). A control group is necessary to test for potential external effects between the tests (Lienert & Raatz, 1998).

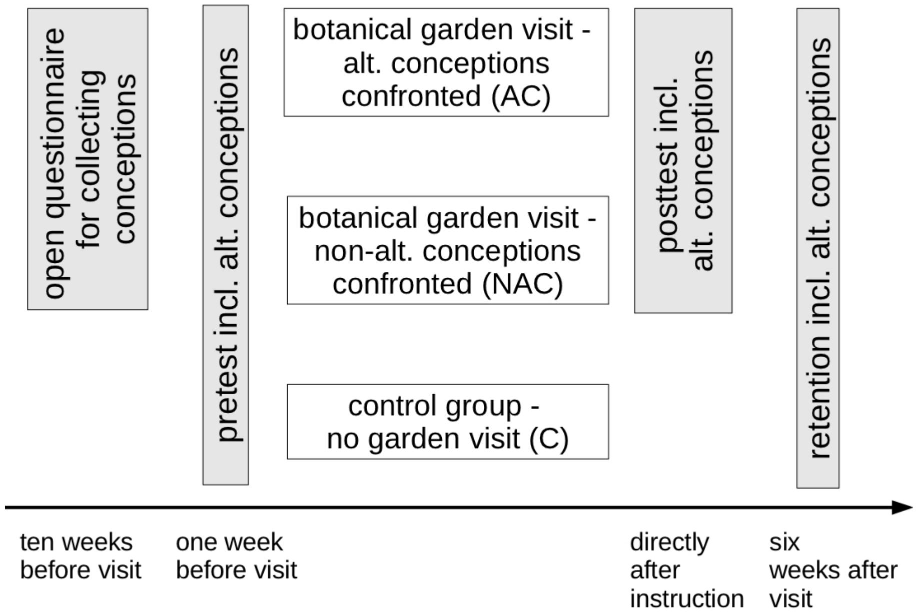

Figure 4.1: *Schematic representation of the study design. Performed tests are shown in gray, the arrow below denotes progression of time.*

We assessed the quality of our questionnaire by applying a Rasch model using the R-package "eRm" (version 0.15; Mair & Hatzinger, 2007). We performed Andersen's likelihood ratio test (Andersen, 1973) and found no significant deviation from the assumption of a Rasch model being valid ($X^2 = 9.33$, df = 9, $p = .41$). Thus, the prerequisites of a Rasch model are met (items are powerful, not strongly correlated and unidimensional; Koller et al., 2012). Thus we expect our questionnaire to allow for reliable results regarding the cognitive achievement of the students.

2.4 Statistics

To test, whether students within both intervention groups learned, or forgot, respectively, between the different test times (pre-, posttest and retention) we conducted Wilcoxon signed rank tests for each possible pairing of test time. To counteract the problem of multiple comparisons, significance values were corrected using the Bonferroni-Holm method (Holm, 1979). Note that for the control group only pretest and retention could be compared, as no posttest was performed for these students.

We further tested for the influence of the instructional method (AC vs. NAC) using Mann-Whitney U tests for all three test times.

3. Results

Both instructional approaches changed the conceptions of bionics and the lotus effect in the students' minds from the pretest to the posttest significantly (see Fig. 4.2a, b; Table 4.2). For the pretest, shown in Figure 4.2a, apparently the NAC group knew more about the topic than the AC group, as the median was one score higher for the first one. However, they did not differ significantly, also not with regard to the posttest (Table 4.3). Thus, the short-term learning outcome was similar and comparably high, resulting in an increase of the students' knowledge of approximately four scores for both groups (see Fig. 4.2a, b). From posttest to retention that group, which was confronted with their alternative conceptions, forgot more than the non-confronted group (see Fig. 4.2b, c; Table 4.2). Consequently, testing for retention revealed that the two groups differed significantly in their knowledge (see Table 4.3). In general, the long-term learning outcome was higher for the NAC group (see Fig. 4.2c), but both groups learned and changed their conceptions significantly over the whole progress of the study (see Table 4.2). The control group neither increased nor decreased their knowledge (Table 4.2).

Table 4.2: *Results of within-group comparisons of scientific concepts between all possible combinations of test time. We used Wilcoxon signed rank tests with Bonferroni-Holm correction of p-values.*

Group	**Pretest vs. Posttest**		**Posttest vs. Retention**		**Pretest vs. Retention**	
	W	*p*	W	*p*	W	*p*
C (n=57)	-	-	-	-	579.0	.673
AC (n=128)	171.0	< .001	7966.0	< .001	1074.0	< .001
NAC (n=132)	119.5	< .001	3063.5	< .01	97.0	< .001

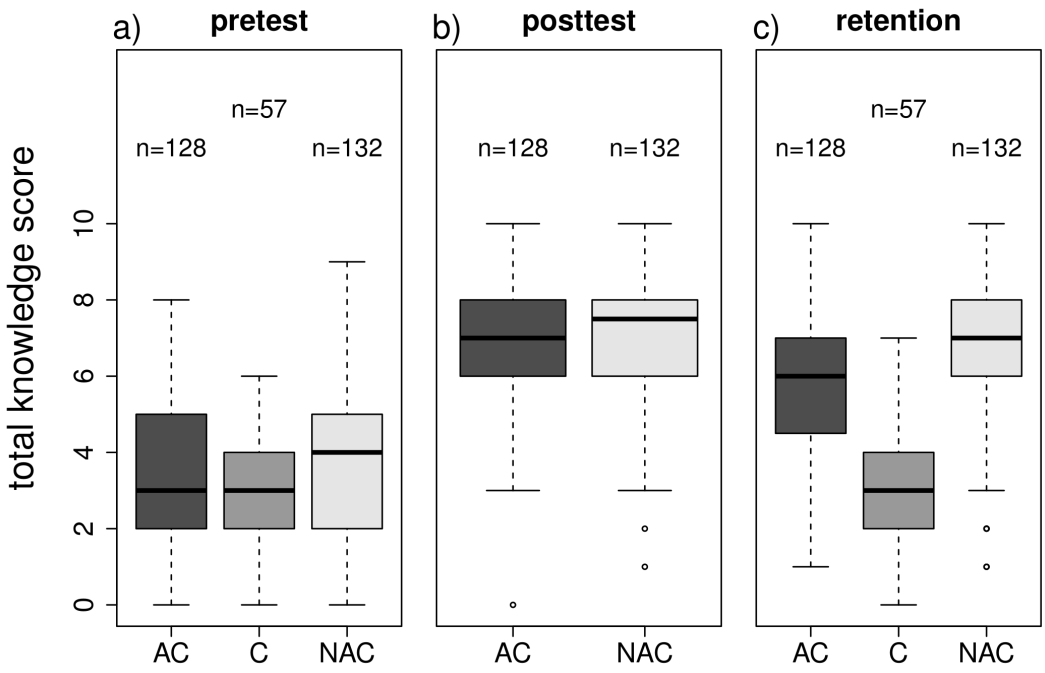

Figure 4.2: *Total knowledge scores of the two teaching methods and the control group for a) pretest, b) posttest and c) retention. "AC" - confronted with alternative conceptions, "NAC" - not confronted with alternative conceptions, "C" - control. Note that directly following the intervention (posttest) the control group's knowledge was not assessed.*

Table 4.3*: A between-groups comparison (AC vs. NAC) of scientific conceptions for the three test times, using Mann-Whitney U tests.*

Test time	**AC vs. NAC (Mann-Whitney U Test)**	
	W	*p*
Pretest	17490.5	.921
Posttest	17634.5	.811
Retention	20630.5	< .002

4. Discussion

We hypothesized that students who were confronted with their alternative conceptions changed these significantly more than those, who were not confronted. In contrast our results revealed that students of the AC group changed their conceptions less than those of the NAC group to a scientifically correct view over longer time scales.

Our study design was similar to that of Franke and Bogner (2011b), yet we obtain contrary results for posttest and retention. Franke and Bogner asked students of only one class participating at a genetic lab day for their alternative conceptions. We asked all participating students about their concepts, which allowed us to assure that at the time of the intervention all individual students have had at least once heard something about bionics and the lotus effect (even if through the assessment questionnaire it was the first time). A second difference is that Franke and Bogner (2011b) renounced the last phase, the review of the changed ideas (Driver, 1989), which we implemented in the discussion of the experimental results – this might be the crucial point.

Surprisingly the NAC students learned nothing at the genetic laboratory in the study of Franke and Bogner (2011b), while the learning achievement of the AC students was highest in the present study. Our study showed no negative effect on students' scientific conceptions and our teaching methods did not confuse the students. Furthermore we assume that a test directly following the instruction should result in similar knowledge scores for all instructional approaches, since the students will have heard the correct scientific view a few moments before. Consequently for the posttest researchers should rather not consider an improvement of the scientific conceptions. Here the posttest is only an instrument to measure actual knowledge, hence to show that the instruction in general was successful and to measure, if and how many of the students forgot from the posttest to the retention. This is in accordance with Pöhnl and Bogner (2013a), who also find that the learning achievement of groups with a confrontation with alternative concepts was as high as the success of groups, which were not confronted at the posttest. However, in their study the AC students forgot more than the other instructional group. The researchers explain the results of the posttest rather as an addition of new informations to existing knowledge (Vosniadou, 1994) than a deep restructuring (Vosniadou et al., 2008).

With regard to the instructional design we tried not to overstrain the students (i.e. overwhelm their comprehension), like Pöhnl and Bogner (2013a) have done with refutation texts. However, we obtain similar results for the AC group. These two different instructional designs did not foster the conceptual change process following Posner et al.'s theory (1982). We cannot exclude that the students were also cognitively overloaded as a consequence of our instructional design. The dissatisfaction with their already existing concepts via confrontation (i.e. the conflict) is the most difficult and delicate point within the whole process (Limón, 2001). Consequently, the instructional design should be selected very carefully by the teacher. It is thus very likely a mixture of two to three methods could be more successful to eliminate student alternative conceptions (Çalik et al., 2010).

This study was ideal to be conducted in a botanical garden. At this out-of-school learning setting the students have the opportunity to see the lotus plants, even though the experiments themselves were conducted using *Tropaeolum* plants. However, we assume that any learning setting is appropriate to conduct the teaching methods applied here, although obtaining the relevant resources (e.g. plant specimens) may prove more difficult in alternative settings.

4.1 Limitations of the study

The assessment of the alternative conceptions was solely based on a questionnaire with knowledge questions, which could be seen as a downside of this study. However, Lewis, Leach and Wood-Robinson (2000) and Franke and Bogner (2011b) already showed that the usage of knowledge questions is an appropriate way to obtain the students' conceptions, although some students may be discouraged by such questions. Nevertheless, some interviews regarding the knowledge and conceptions of the students would have surely been beneficial for our study (see e.g. Duncan & Reiser, 2007), but we did not have the means to gather these. Additionally, the teacher in our study visited every class and repeatedly explained to the students that they should only answer questions, for which they already had some conceptions, and insisted on the impossibility of wrong answers.

One factor that should not be overlooked is the prior knowledge of the students about the lotus effect. The students were quite familiar with some topics (e.g. surface tension of the water), whereas others were completely new to them (e.g. water-repellent surfaces). As can be seen in Figure 4.2, the groups differed slightly during the pretest. Limón (2001) states that it is difficult to expect any conceptual change in case that the students' understanding of the new information is so low that the conflict might not be meaningful, if they have little knowledge about a topic. It might thus be that the intervention was not relevant for the AC group, as this one showed less knowledge before the treatment. Hence, these students would not have adopted the scientifically correct models over the longer term.

Vosniadou and Ioannides (1998) argued that conceptual changes are in many cases a slow and gradual process over the childrens' whole development. As such, it is not very easy to induce this change in students. It might thus be a problem within our study that the couple of hours, in which the students worked on the topics, were insufficient time to initiate a conceptual change process. Teachers, however, have more time to work with the students throughout the whole school year, which might thus increase the effect of a conceptual change approach.

5. Conclusions

With this study we cannot support Posner et al.'s (1982) theory of the process of conceptual change. In this case the changing of the concepts of the students was more successful without the confrontation of the students' alternative conceptions. Although we tried not to overstrain the students with the usage of pictures combined with models and a dialogue with the teacher to induce a dissatisfaction with the own false view of the scientific topic, the students which were confronted with their alternative conceptions forgot more over a longer time scale. Probably the alternative conception pictures were so incisive and memorable that the students rather remembered these instead of the scientifically right ones.

For future studies we would recommend to lay focus on different methods of confronting students with their alternative conceptions at out-of-school learning settings. Additionally, a point that may be worth to think about is, how students react to the applied methods, who already have had the scientifically correct conceptions of a given topic. We would assume that in these cases the students would likely rather get confused than confirmed in their understandings.

Due to the fact that many studies (Franke & Bogner, 2011b; Çalik et al., 2010; Duit et al., 2008) obtained contrary results, we conclude that confronting students with their alternative conceptions is not necessarily the best method to change the conceptions successfully. The educator should carefully balance the effort and the benefit of going the step by step conceptual change way. Surely the teacher who knows the students from every day school life over years is better able to adapt the program for the students and to estimate their cognitive possibilities. Additionally, the conceptual change process is a slow and gradual learning process (Limón, 2001). This is the reason why the teachers in school should procure correct scientific mental models and not only the out-of-school settings, where the students usually pass one day during their school life. Still, our results show that a visit at a botanical garden can be worthwhile and may also foster a conceptual change process.

CHAPTER V CONCEPT MAPPING ABOUT *PLANTS AND WATER*: A USEFUL CONSOLIDATION TOOL FOR FEMALES AND A USEFUL RECAPITULATION TOOL FOR MALES[3]

1. INTRODUCTION

Nowadays concept maps have a great value for the teaching of natural sciences and are theoretically profound and powerful tools for capturing, representing and archiving knowledge, as well as to create new knowledge (Novak & Cañas, 2008). Still, this method is rarely applied by teachers, although they could use the method of concept mapping to request the students' knowledge and understanding of new topics, to reveal students' misconceptions and ideas (Kinchin, 2000). Concept mapping further fosters meaningful learning, consequently students' misconceptions could be overcome (Novak & Cañas, 2008; Novak, 2002). From the students' point of view concept mapping contributes to build a socially cooperative and constructivistic atmosphere (Valadares, Soares & Torga, 2008), because they often work in dyads or triads and create their individual maps. Additionally, concept maps are helpful for students to "develop an understanding of a body of knowledge, accessing prior knowledge, and exploring new informations and relationships" (Gersten & Dimino, 2008, p. 643; Bulgren, Schumaker & Deshler, 1988), which results in a consolidation of knowledge. A lot of qualitative and quantitative studies in the last two decades showed the positive effects of concept maps as a consolidation phase on the students learning success and their ability to reason (Gerstner & Bogner, 2009; Conradty & Bogner, 2010; Baldoni & Antonietta, 2012). For the present study we applied concept mapping as a form of consolidation and additionally as a means of recapitulation of new knowledge in combination with guided workstations at the out-of-school learning setting botanical garden.

1.1 Concept mapping to consolidate and recapitulate new knowledge

Concept maps are theory-driven graphic organizers (Trowbridge & Wandersee, 1998), which are hierarchically structured. The maps include concepts and connecting words, concerning a given topic. The relationships between these are connected by a linking line (Fig. 5.2). Words

3 This chapter is submitted to International Journal of Science Education as: Kubisch, F., Gerstner, S., & Heyne, T. Concept mapping about *plants and water*: a useful consolidation tool for females and a useful recapitulation phase for males.

on these lines refer to linking phrases and build a meaningful proposition (Valadares et al., 2008; Novak & Cañas, 2008). Concept mapping represents conceptual knowledge structures (Novak & Gowin, 1984; Novak & Musonda, 1991; Trent, Pernell, Mungai & Chimedza, 1998) and promotes meaningful learning (Liu, Don & Tsai, 2005), which is the key concept in the educational process (Ausubel, 2000; Novak, 1998). Another positive effect of this educational method is that the student can learn how to learn. The learner can reflect about his/her actual knowledge and abilities and consequently improve his/her self-awareness (Kao, Lin & Sun, 2008). Several studies in the last years applied concept mapping before and after an instruction to evaluate the instruction and to measure the effect on the students' concept maps (Schaal et al., 2010; Muscat, 2013; Judson, 2012). Generally, concept mapping was found to be an appropriate evaluation method for instructions. Furthermore concept maps "are always an efficacious tool to reinforce and consolidate knowledge" (Baldoni & Antonietta, 2012). With this study we focus on the value of concept mapping as a means of consolidation after an instruction. Conradty and Bogner (2010) measured significant correlations between the complexity of the concept maps and the knowledge acquisition for 6th graders. Consequently, they concluded that concept mapping "could be an adequate consolidation phase" (Conradty & Bogner, 2010, p. 56). For 5th graders Gerstner and Bogner (2010) found a higher increase in the short-term knowledge for students using the concept mapping approach. In the present study we also used concept mapping to consolidate and deepen students' new knowledge about *plants and water* directly after an instruction at a botanical garden with 8th graders. Following that we measured the effect of the consolidation phase with a multiple-choice-questionnaire in comparison with a non-concept-mapping-group (NCM). With regard to the results of Conradty and Bogner (2010) as well as Gerstner and Bogner (2010) we hypothesized for this class level that:

1. *Concept mapping as a consolidation phase after an instruction in the botanical garden leads to higher knowledge scores for the short time than no concept mapping.*

Gerstner and Bogner (2010) additionally observed no effects on the retention rate six weeks after the instruction, and even found negative effects on the decrease rate in comparison to a group without concept mapping as a consolidation phase. Consequently, a second question arises from these results: how can the acquired knowledge be preserved over long times scales? The repeated concept mapping process over time leads to a development from crude ideas to a sophisticated and complex conceptualisation (O'Connor, 2012). Thus, we suppose that a late recapitulation of concept mapping helps the students to better remember the contents of the instruction. Thus in our present study one group of students created an additional concept map six weeks after the instruction, as a form of recapitulation. The students made these concept maps directly before a retention knowledge test to measure the effect of this concept mapping. We want to test, whether a concept is usable as a follow-up method before a test, without repeating the matter of the instruction. We hence also applied the concept map as a means of recapitulation and hypothesized:

2. *Concept mapping as a recapitulation tool six weeks after an instruction in the botanical garden leads to higher knowledge scores for the long time learning success than no concept mapping.*

1.2 Concept maps and gender effects

The opinion that males were better scientists than females was shared by many teachers and researchers for decades. But in the last years this gap between males and females has been reduced. Females caught up in natural sciences. In the Pisa assessment of 2006 there were no strong differences in achievement between genders in 57 countries (OECD, 2006). Only in mathematics females showed lower abilities than males. Udeani and Okafor (2012) think that the reasons for the reduced differences are the diverse and variable instructional strategies in science nowadays. The results of their study about slow learners in 2012 weakened their hypothesis that females in the concept map group achieved higher knowledge scores than males. Previously, several researchers had found positive effects of meta-cognitive strategies like concept mapping especially on females (Jegede, Alaiyemola & Okebukola, 1990; Kelly, 2007; Lewis, 2006). With this background our third and fourth hypotheses for this study are:

3. *Concept mapping as consolidation phase after an instruction in the botanical garden leads to a higher cognitive achievement in females compared to males.*
4. *Concept mapping as a recapitulation tool six weeks after an instruction in the botanical garden leads to a higher cognitive achievement in females compared to males.*

1.3 Guided learning at workstations at the botanical garden

Sellmann and Bogner (2013), Drissner et al. (2010), as well as Wiegand et al. (2013), had shown that botanical gardens are adequate and promising out-of-school-learning settings for instructional research studies. All participants of these studies gained knowledge, for a short and for a long time period, within this open and socially interactive (Hofstein et al., 2001) learning environment. For the present study we used a *guided learning at workstations* (Heyne & Bogner, 2012) to instruct students about *plants and water*. Therefore, we arranged seven workstations in a greenhouse with plant material, material for experiments and illustrations. The workstations' concept was adapted to the principles of natural scientific research. A preservice teacher guided groups of approximately 15 students through these workstations. The students saved the results of experiments and the dialog with the teacher in their own respective workbooks. In comparison to a self-determined learning at workstations, where no teacher interacts with the students, we found no differences between the two instructional methods for the learning outcome and the motivation of the students (Wiegand et al., 2013). Therefore it is legitimate that in the current study students of both treatments, either with (CM) or without (NCM) concept mapping, only passed through guided workstations.

2. METHODOLOGY

2.1 Participants

With 141 8th grade students we performed this study in the summer of 2011. The median of the students' age was 14 years. They came from seven, lower Franconian “Mittelschulen”. These students graduate their school time at 10th grade and achieve a mid-level graduation. The 110 participating students visited the botanical garden of the University of Würzburg for one day and were divided into a group, which developed concept maps to consolidate and recapitulate (CM, n=35), and a second group, not creating concept maps (NCM, n=75). The remaining 31 individuals formed the control group (C). They did not visit the botanical garden for a field trip (Fig. 5.1). 62 of all students were males and 79 were females. The classes were randomly assigned to either of the two treatments.

2.2 Research design

Our approach is quasi-experimental, the design is a before-after/control-impact design as described by Randler and Bogner (2009). The control group is indispensable to test a potential external impact between the whole testing period of approximately eight weeks (Lienert & Raatz, 1998). The pretest was conducted one week prior to the garden visit to measure the already existing knowledge of the students about *plants and water.* Therefore all students had to answer a multiple-choice-test with 15 questions in their classroom (for more details about the questionnaire and the workstations see Wiegand et al., 2013). Immediately after the instruction, the CM-students developed their first concept map. After that they filled out the posttest, while the NCM-group only completed the posttest at the botanical garden. The posttest aimed at assessing the short-term cognitive outcome of the instruction and/or the consolidation phase. Six weeks after the garden visit the CM-group recreated a concept map. Then we assessed the long-term learning success of both the CM and NCM-group with the retention test in the classroom. The control group (C-group) only got the two questionnaires of the pretest and the retention, without a field trip (see Fig. 5.1).

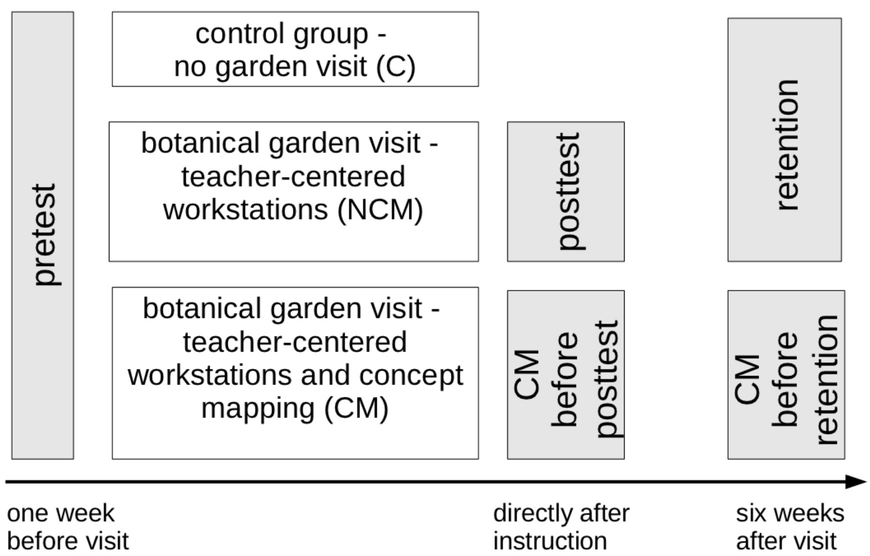

Figure 5.1: *Design of the present study. Time proceeds from left to right (arrow), performed tests are shaded in gray.*

We analyzed the quality of our questionnaire by applying a Rasch model using the R-package "eRm" (version 0.15; Mair & Hatzinger, 2007). Using Wald tests of the single test items, we eliminated one item. Thus, our further analysis are based on 14 out of the original 15 questions. Afterward we tested for validity of a Rasch model using Andersen's likelihood ratio test (Andersen, 1973). We found no significant deviation (X^2 = 14, df = 14, p > .5). Thus, the items are to a satisfying degree powerful, unidimensional and not strongly correlated (Koller et al., 2012). Thus we can assume our questionnaire to allow inference of the latent cognitive traits of the students.

For the teacher-centered workstations every participant received a workbook to save individual results. These workbooks were adapted to the teaching method and contained only questions regarding the stations. The program itself consisted of two lessons, with an overall duration of approximately 90 min (see Table 5.1). Following a teacher-centered introduction concerning the plants' needs for water (approx. 30 min), the teacher introduced the workbook, which was relevant for the success of the interventions (Sturm & Bogner, 2008). The CM-group additionally got a short introduction into the method of concept mapping, after the workstations. The following consolidation phase with concept mapping took 30 min (Table 5.1, for details about concept mapping see below). The teacher who guided the students during the workstations was a preservice teacher holding a first state examination with biology as major subject.

Table 5.1: *Time schedule of the instruction during the botanical garden visit for two treatments.*

Teaching unit steps	teacher-centered workstation group with CM (CM)	teacher-centered workstation group without CM (NCM)
30 min	Introduction *plants' needs for water*	Introduction *plants' needs for water*
90 min	Introduction in the workbook and guided learning at workstations	Introduction in the workbook and guided learning at workstations
10 min	Introduction of concept mapping	-
30 min	Consolidation phase (CM)	-

2.3 Concept mapping

As this method was completely new to the participating students, they got a short introduction by the teacher on "how to make a concept map?" using the black board. Moreover, we provided concepts as "post-its" regarding the topic (for example: transpiration, root, root hairs, stomata, leafs, stem, steam etc.) and possible linking words in an envelope, to reduce cognitive load (Nückles, Gurlitt, Pabst & Renkl, 2004) and to foster the exchange and collaboration of ideas in the group discussion (Novak & Cañas, 2008). Afterward the students pasted these basic words around the word "plants" on a big sheet of paper and connected them with linking phrases on arrows to meaningful propositions (Fig. 5.2). 78% of the students created their maps as dyads and 22% as triads. Before letting the students create the second concept maps six weeks after the first one (recapitulation), we omitted the concept map instruction phase.

We analyzed the concept maps following the method of Kinchin et al. (2000). We counted right and reasonable connections, nets, spokes and chains. The results of this qualitative approach will only be mentioned in the discussion.

2.4 Statistics

To test, whether students within all three intervention groups showed changes in their knowledge scores between the different test times (pre-, posttest and retention) we conducted Wilcoxon signed rank tests for each possible pairing of test time. Additionally, we calculated the absolute differences between knowledge scores for all possible combinations of tests (pre- and posttest: increase rate; posttest and retention: decrease rate; pretest and retention: retention rate). These total knowledge score differences were compared using Mann-Whitney U tests. To counteract the problem of multiple comparisons, significance values were corrected using the Bonferroni-Holm method (Holm, 1979). As the control group students did not participate in the posttest, only pretest and retention were compared. We also tested the influence of the instructional method (NCM, CM, C) and of the gender using Mann-Whitney U tests for all three times of test.

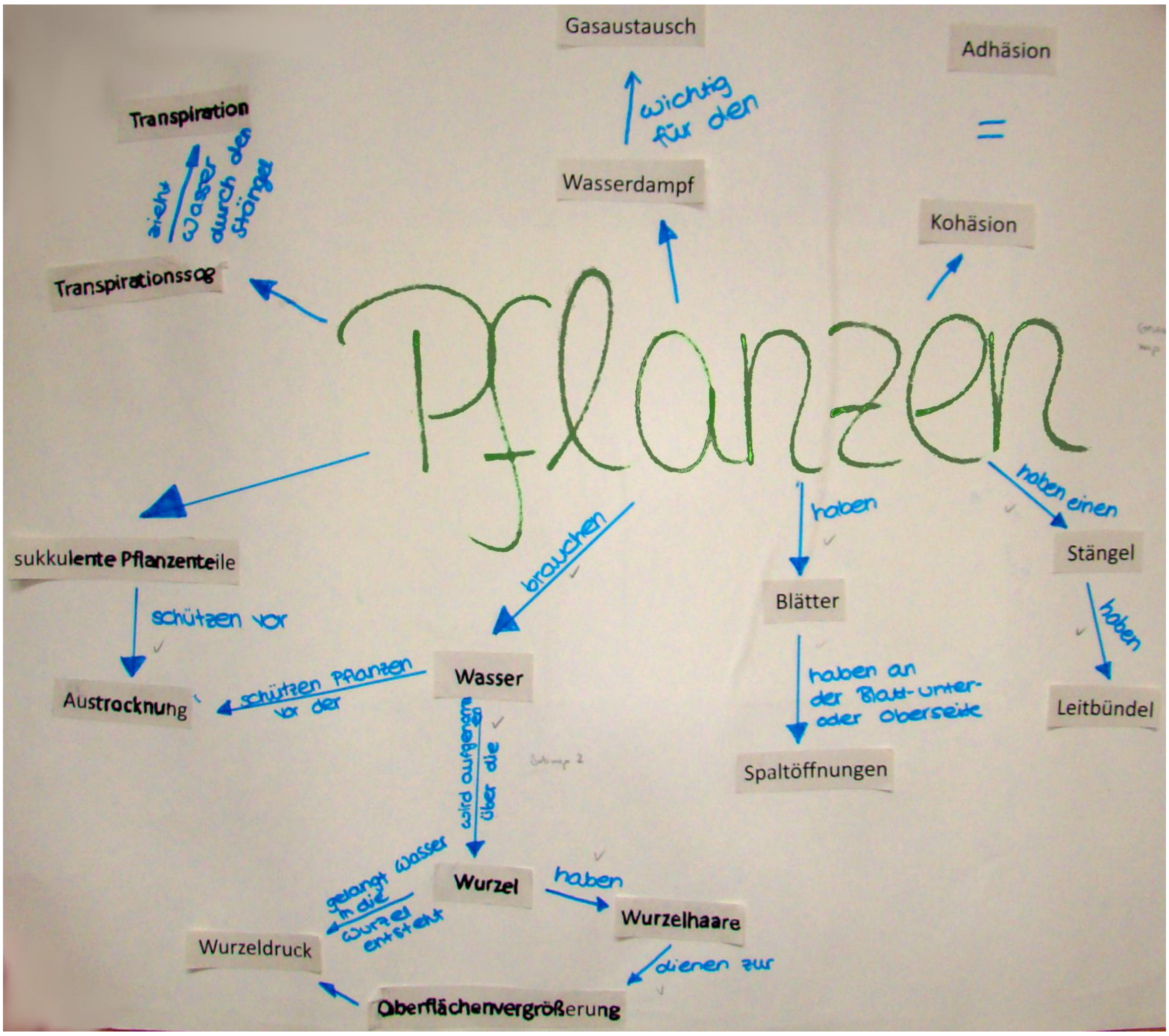

***Figure 5.2**: Photo of an exemplary concept map, created by two participating students.*

3. Results

3.1 Between-group comparison

Already at the pretest we found significant differences of the students' knowledge about *plants and water* between the two treatments (Table 5.2; for the medians and 25% - and 75% quartiles of the knowledge scores see Table 5.3). The group, which developed concept maps, showed lower initial knowledge compared to the NCM-group. However, there were no differences between the two groups at the posttest and retention regarding their knowledge scores. In comparison to the control group students of both treatments increased their knowledge significantly towards the retention (C vs. NCM: W = 1788, $p < .001$; C vs. CM: W = 892, $p < .001$).

Table 5.2*: A between-group comparison (NCM vs. CM) for the three test times, using Mann-Whitney U tests.*

Test time	**NCM vs. CM (Mann-Whitney U Test)**	
	W	*p*
Pretest	1717	< .02
Posttest	1146.5	.282
Retention	1253	.702

Table 5.3*: Overview of the assessed knowledge scores for test times and treatments. Given are the median values, the numbers in brackets denote 25% - and 75% - quartiles, respectively.*

Treatment	**Test time**		
	pretest	posttest	retention
C (n=31)	7 (6, 8)	- (-,-)	6 (5, 7)
C_{male} (n=13)	8 (6, 8)	- (-,-)	6 (6, 7)
C_{female} (n=18)	7 (6.25, 8)	- (-,-)	6 (5, 7)
NCM (n=75)	7 (5, 8)	10 (9, 11.5)	9 (7, 10)
NCM_{male} (n=36)	6 (6, 8)	10 (9, 11.25)	9 (6.75, 11)
NCM_{female} (n=39)	7 (5, 8)	10 (9, 11.5)	9 (7.5, 10)
CM (n=35)	6 (4.5, 6.5)	10 (9, 12)	9 (7.5, 10)
CM_{male} (n=13)	6 (5, 7)	10 (10, 11)	9 (9, 10)
CM_{female} (n=22)	5 (4, 6)	11 (8.25, 12.75)	8.5 (7.25, 10)

Figure 5.3a shows an increase of knowledge for both treatments of approximately five scores from pre- to posttest. Still, the increase of the CM-students was significantly higher than that of the NCM-students (W = 944.5, p = .017). Both groups forgot about one to two scores (Fig. 5.3b and Table 5.4). All instructed students retained knowledge over a longer time period (Fig. 5.3c and Table 5.4) and both treatments differed significantly from the control group (C vs. NCM: W = 1869.5, p < .001; C vs. CM: W = 951.5, p < .001). The CM-group showed an approx. two scores higher retention rate than the NCM-group, which was not significant, but a trend could at least be determined (W = 1028.5, p = .067).

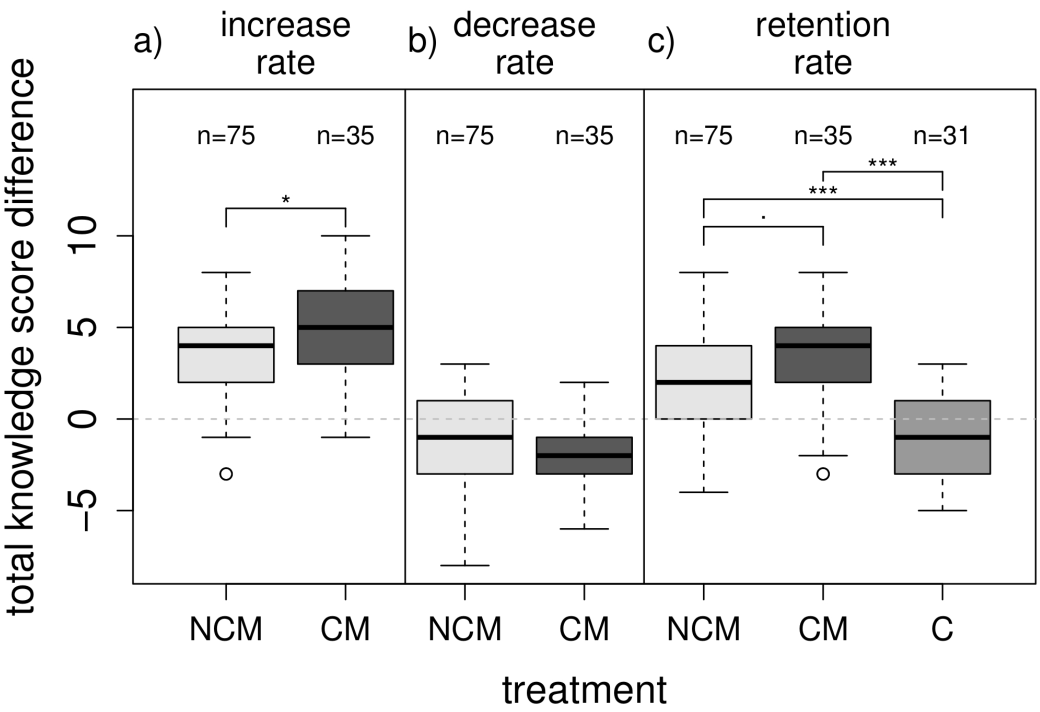

Figure 5.3: *Increase rate (a), decrease rate (b) and retention rate (c) of knowledge for the participating students, which did (CM) or did not create concept maps (NCM) and the control group (C). Above each box the sample size is given. Significance indicators result from Mann-Whitney U tests. *** p < .01, * p < .05, . p < .1*

Table 5.4*: Results of within-group comparisons between all possible combinations of test time. We used Wilcoxon signed rank tests with Bonferroni-Holm correction of p-values.*

Group	**Pretest vs. Posttest**		**Posttest vs. Retention**		**Pretest vs. Retention**	
	W	*p*	W	*p*	W	*p*
C (n=31)	-	-	-	-	229	.073
NCM (n=75)	112	< .001	1446.5	< .001	359	< .001
CM (n=35)	2	< .001	385.5	< .001	32	< .001

3.2 Gender

Especially the pretest scores of the females at the beginning of the study differed significantly between the treatments (Table 5.3). The Mann-Whitney U test of the NCM-females and the

CM-females resulted in a significant *p*-Value of .014 (W = 592). Females from the control group knew, as did the NCM-females, significantly more than those from the CM-group at the pretest (W = 78.5, $p < .002$). Except for the males of the CM treatment, all groups forgot significantly from posttest to retention (Table 5.5). However, from pretest to retention all treatments led to significant knowledge changes, when analyzed separately for each gender. The increase rate of the females, which created a concept map, was higher than that of the NCM-females (W = 276.5, $p = .02$).

Table 5.5: *Results of within-group comparisons with respect to treatment and gender between all possible combinations of test time. We used Wilcoxon signed sum tests with Bonferroni-Holm correction of p-values.*

Group	Pretest vs. Posttest		Posttest vs. Retention		Pretest vs. Retention	
	W	*p*	W	*p*	W	*p*
NCM_{male} (n=36)	187.5	< .001	839.5	< .05	411	< .005
NCM_{female} (n=39)	202	< .001	1055.5	< .005	385	< .001
CM_{male} (n=13)	14.5	< .001	114.5	.118	36	< .02
CM_{female} (n=22)	14	< .001	352	< .01	52.5	< .001

4. Discussion

4.1 Between-group comparison

With regard to our first hypothesis we confirm the results of Gerstner and Bogner (2010), because the CM-group starts with lower knowledge about *plants and water,* but experienced such a strong increase in it after the instruction and consolidation phase that we did not find any differences at the posttest (Table 5.2). Even though the knowledge of the CM-students was not higher than that of the NCM-students at the posttest, the increase rate was significantly higher (Figure 5.3). Consequently, our findings and those of Gerstner and Bogner (2010) support, that concept maps are a valuable method to consolidate knowledge after a teacher-centered instruction, especially for secondary school students, although they were novices.

Haugwitz et al. (2010) detected that concept mapping as summarization was only advantageously for students with lower cognitive abilities. In accordance to that and the results of Udeani and Okafor (2012), who found that slow learners profited mostly from the concept mapping method, we found for the initially weakest group (CM-group) the strongest increase in knowledge. With regard to the school type (mid-level achiever) and their low initial knowledge they could be compared to slow learners. Thus, concept mapping is an appropriate method of consolidation for lower achiever students, even though a lot of studies in Germany were focused on high-achievers (Gymnasium) (Conradty & Bogner, 2010; Gerstner & Bogner, 2010; Schaal et al., 2010).

Second, we hypothesized that concept mapping as a recapitulation tool should lead to a higher long-term learning success of the students. However, our results do not support that. The students, who developed concept maps, forgot as much as the students, who didn't take part in a recapitulation phase. We would have expected that especially the basic words provided to the students, who created concept maps (see methods section), should help them to mobilize their knowledge gained during the instruction. Additionally, at that point they were no novices with regard to concept maps anymore, supporting the expectation that the repetition of this method should increase sophistication and overall comprehension (O'Connor, 2012). There is a lack of literature with regard to concept maps as a means of recapitulation of knowledge. This fact and our results lead to the conclusion that concept mapping is not the method of choice to recapitulate new knowledge, if considering females and males simultaneously.

4.2 Gender effects

The differences between the two treatments at the pretest were coincidental and mainly caused by the CM-females, whose knowledge about *plants and water* was significantly lower than of those of the NCM- and C-group, respectively. Simultaneously, the increase rate of the CM-group females was highest (data not shown). These facts verify our third hypothesis that especially females profit from the concept mapping as a consolidation phase. Here we are again in accordance with Udeani and Okafor's results (2012). The slow learning females in the concept mapping group at their study "performed better than their male counterparts" (p. 139), whereas Gerstner and Bogner (2009) found no gender effects, neither for the short time nor the long time learning success. From that we tend to conclude that concept mapping as a consolidation phase was very beneficial for the females because they were weaker in the beginning.

Our fourth hypothesis was contradicted by our data. Not the females, but the males profited from a recapitulation using concept mapping, as they were the only group, which did not forget significantly. Conlon (2004) found that males experience the creation of concept maps rather as hard work, compared to females. Probably it was similar in our study for the first concept map. The second one could have been easier for them and helpful in remembering the contents of the intervention. The concept map directly after the instruction meant 40 minutes more work load. Given that the male students experienced it as harder work, this might also have led to a more intensive recapitulation of the topic.

Furthermore there can be gender effects with regard to concept structure and complexity. Gerstner and Bogner (2009) detected with the method of Kinchin et al. (2000) that females produced more net structures than their male counterparts. As a consequence of the nets (three and more), which presumably reflect a meaningful learning (Kinchin et al., 2000), these females showed a higher long-term learning success. That means that the structure of a concept could be an indicator for the learning success over long time. We analyzed the concept maps of our students also with the methods of Kinchin et al. (2000). We did, however, not find any nets, neither in the first, nor in the second concept maps. The structures we could detect were submaps, spokes and chains. This could explain, why the females forgot much over the longer term and did thus not show meaningful learning. These qualitative results support again that novices produce concept maps with poor coherence (Cañas et al., 2003; Koponen & Pehkonen, 2008).

4.3 Limitations

It would have been helpful for our understanding, if we could have specified the qualitative structuring of the concept maps (as shortly described above) in more detail. Unfortunately, the sample size of the students was too low, so we had to concentrate on the analysis using knowledge scores.

To better resolve the problem of concept mapping as consolidation or recapitulation phase, it would also be even more helpful to repeat a similar study with two more groups – one that creates concept maps only as consolidation phase and one that does it only for recapitulation. In our study in the botanical garden we had, however, to investigate other topics as well. Thus we had too little time to include more groups than we did.

5. Conclusions

In our opinion there are two reasons, why teachers rarely use concept maps: the high temporal demands of the method in comparison to a school lesson and a lack of awareness of the advantages of this method. However, with this study we could show that concept maps can, depending on their application, be very good means of recapitulating or consolidating knowledge. Especially weaker students show a strong increase in knowledge given the application of this method. We would advise to include concept mapping in curricula, which should already be defined by a mix of different methods, to foster learning in both genders and weaker students. Thus, the type of application should be varied as well. In our case concept maps for consolidation were particularly helpful for the females to rapidly deepen and save their knowledge. In case of recapitulation it was the males, who forgot less after applying this method.

CHAPTER VI DISCUSSION

1. GENERAL DISCUSSION WITH REGARD TO EDUCATION AT BOTANICAL GARDENS

A botanical garden can and should be a place to try and touch, and especially because of that it should be attended by teachers and their classes to complete the curriculum. The educational personnel in the botanical gardens should try to use many different methods (instructivistic and constructivistic) for an instruction and its evaluation, allowing for an efficient learning of all kinds of learners. With respect to the application of conceptual change it is evidently not very easy to use in school. However, especially then it is useful for teachers to use the opportunities of out-of-school learning settings, which are increasing due to the current scientific know-how and the diversity of materials and originals present there.

The methods I applied and the curricula were very well applicable in the botanical garden and always led to significant long-term knowledge increases. Thus the botanical garden as an out-of-school learning setting is a good and versatile extension of everyday school life for 8th graders. Also the further application of the methods with school classes, which attended the garden for means of teaching university students, was successful.

The students' comparably high interest in the topic (chapter III) indicates that botany was for them not as uninteresting as one would probably expect. Of course, the little role that plants play in the German curricula, despite their fundamental relevance for life, including humanity, results in a certain level of *plant blindness* (Wandersee & Schussler, 2001). My pretests, however, which I performed with the students for chapter III, showed high results. Certainly plant blindness can not be decreased efficiently, if the curricula can not be changed. Nevertheless, I want to highlight the important task of educators / teachers in botanical gardens – they can make these settings places, where the instructions can motivate, awake interest and thus result in a better comprehension of plants (but also for other topics and subjects).

The fact that I did not find very strong differences between most treatments can be caused by the fact that every one of my three studies was designed to be constructivistic and very practical, which fulfilled the demands of Confucius. This might also explain the always significant long-term learning success of the students on *plants and water* and the lotus effect, as well as their high interest. The hands-on elements and the experiments should, however, be designed such that the students know exactly, what they are doing, otherwise they will not understand the contents. This might for example happen at an out-of-school learning setting like laboratories, where the students mix different fluids, of which they neither, what exactly they affect, nor why that is necessary (Abrahams & Millar, 2008). Yet, if these “black boxes” do not exist, so the students know what they do and hypothesize on it before, practical working is beneficial, especially for learner types like sensors (http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/styles.htm, accessed 14 July 2014).

In addition to the given working materials and instructions during my studies, one crucial reason for the learning success of the students certainly was the (slight) guidance by the teachers or pedagogues (regardless of them being supporters or rather moderators). Thus I did not perform a completely free inquiry-based learning, which is criticized by Novak and Cañas (2008). That means for the education in botanical gardens, that one should always take care of some guidance within the instruction.

Of course all studies at out-of-school learning settings necessarily have some flaws. It is for example always possible that the students are disturbed by garden visitors or through gardening practitioners. Also, from the side of the responsible teachers these days were designed like common school trips, which increased the probability of the classes for being late or having to leave before the intended end of the program. Thus the given time schedules could not always be followed exactly.

2. Advanced discussion of the results of the applied methods

2.1 Guided learning vs. self-determined learning at workstations

This part of my work shows that the teacher's involvement had no influence on the learning success and the interest of the students, while learning at workstations. I suspect this to be a consequence of the well created material and the circumstance that the students were involved actively at the individual stations. This result thus confirms the successful application of hands-on elements and experiments in instructions of other studies (Thair & Treagust, 1997; Scharfenberg et al., 2007; Randler et al., 2011; Heyne & Bogner, 2012) as well as the saying by Confucius, which I mentioned in the beginning of this thesis. However, a certain degree of guidance is inevitable, as pure inquiry-driven learning is shown to be rather counteracting conceptual understanding (Novak & Cañas, 2008). Basically, both treatments I applied in chapter III could be considered to be "guided inquiry", although I explained one of these as "self-determined". This phrasing relates to the conduction of the workstations, not to the contents or experiments. Those were given by a workbook and the material at the stations, and hence in a way guided. This hints to a shortcoming of this study, as the treatments did not differ fundamentally. It would have been helpful to include a third treatment, consisting of a traditional guided tour. This would also have changed some further parts of the study: I would not have used any originals or experiments, as it was done e.g. by Randler & Bogner (2009). These authors thus also achieved clear results. This was, however, not my intention. Instead, I wanted to apply a teacher-centered method, which, according to personal communication with other educators and my own experience, is already often applied in botanical gardens in Germany, such as guided tours including experiments, many schematic pictures and searching tasks. As I did not find any differences between this and a more strict student-centered approach, I would advise practitioners to stick to this method, train new personnel accordingly and always give the students some kind of workbook to consolidate the acquired knowledge and understanding.

2.2 Conceptual change

At first glance, the instructions during the study described in chapter IV were more successful than those described before. However, the students also came to the botanical garden with lower initial knowledge. Although I have assessed the conceptions of every student, who was later confronted with these, it was of course not possible to confront every participant with his / her own respective conceptions. Yet, I think that this is not necessary, as alternative conceptions are often similar, e.g. those regarding the earth's form (Vosniadou et al., 2008) or climate change (Sellmann & Bogner, 2012). I have had many similar answers in my own questionnaires and collected these into categories. The three most frequent ones were used for the confrontation. In fact, the other answers indicated either correct or wrong conceptions of the remaining students, which does of course not provide a good basis for the conceptual change approach. Those with already correct ideas would not need a conceptual change, but a deepening lesson, whereas the others would have needed an initial introduction or a repetition of the lessons of their 6th grade, respectively. The conceptual change approach following Posner et al. (1982) can lead to strong confusion, which might be the reason for the result that the group, which was confronted with alternative conceptions showed a slightly lower long-term learning success than the group, which learned conventionally. Regarding this topic there is a lack of literature, as usually the focus is laid on students with wrong alternative conceptions. But especially the prior knowledge is the crucial factor in this method (Limón, 2001). In my instructions I concentrated on combining the new knowledge with already existing prior knowledge, as only like that a conceptual change is possible.

Especially regarding botany, groups are often very heterogeneous in their prior knowledge. The conception of this method is thus quite difficult for this out-of-school learning setting. How should one assess alternative conceptions? How should one confront the students with them? A concept map before, created of the students while still being in school, is very costly and means a lot of work of the personnel of the botanical garden. I guess that an initial discussion at the beginning of the instruction is still the most practicable solution, although there those students are overrepresented, who already have correct conceptions. In these moments the instructor should have the didactical skills to not show any signs of whether the ideas are correct, or not. Instead it should be provided as a basis of discussion for all students.

Generally, conceptual change plays a big role in the daily business of educators in botanical gardens, as in botany there are many puzzles and alternative conceptions. The application is, however, not easy to achieve in an exact way for guided tours or guided workstations, like I conducted it during a practical course regarding the lotus effect, and as Posner et al. (1982) thought it to be.

2.3 Concept mapping

I did also not find clear differences between the general treatments in my study on concept mapping at out-of-school learning locations (chapter V). A detailed analysis of the concept maps lead to the result that the knowledge, which indeed was increased due to our instruction (chapter III), could not have been connected optimally (see Fig. 5.2). Our students were novices regarding this method, what might explain the results. This was also the reason for us to equip the students with initial concepts via “post-its”, in order to reduce cognitive load (Nückles et al., 2004). Basically, it would have been good to differentiate between the concept map as a means of consolidation and of recapitulation, with not providing any concepts for the first, but definitely providing them for the latter concept mapping. Two additional treatments would also have been helpful for a better understanding. One group would have only conducted a mapping for consolidation, another one only for recapitulation. However, due to the constraints we had to deal with at the botanical garden that was impossible (see above).

As I already mentioned in the introduction, according to the literature concept maps seem to be ideal tools to test knowledge, but also to consolidate it. Unfortunately our results are probably not very robust, but still they indicate that concept mapping, if used in different ways (consolidation vs. recapitulation) may help different kinds of students. Weaker learners and females seem to profit especially from using it for consolidation, whereas for stronger learners and males it is rather efficient to aid recapitulation. This supports the claim of Kinchin (2000) that concept maps are a tool for any group of learners. Similar to Papanikolaou, Mabbott, Bull & Grigoriadou (2006) I am convinced that one additional group of learners should benefit especially from concept maps for recapitulation: the intuitors, who don't like repetitions (Cristea, 2004). However, repetitions are very usual in traditional education. Probably concept maps could from time to time be used to repeat learned topics, e.g. before written tests (under the condition that the students are not novices and get help with this method). Based on this assumption and my findings one could conclude that males might rather be intuitors than females. Yet, there is no indication in the literature for this hypothesis.

Concept mapping as a method is easy to apply in botanical gardens, especially for consolidation directly after an instruction. The late concept map for recapitulation, however, is then the duty of the according teacher. If the visit to the garden is intended not only to be a school trip, but an expansion of the curriculum, the teacher should do that if advised by a garden's educator.

3. CONSEQUENCES FOR THE EDUCATION OF TEACHERS

It is of utmost importance to confront students with the concepts of learning at workstations already during their studies. It is important to include many hands-on elements and show experiments and, of course, to let them try everything. This also holds for the method of concept mapping. Only from theory it is hard to believe, how valuable this method can be for school students. My results indicate that in the case of a well-prepared learning at workstations program it is of minor importance, whether the teacher acts as a supporter or a moderator. This means that the university students can try to fulfill different roles with different school classes and find their individual way of teaching, what should not have an influence on the learning success of the school students.

At the University of Würzburg the methods used in my studies have already been applied by teaching students with several school classes at out-of-school learning settings, like the botanical garden or laboratories. Taraban et al. (2007) have shown that students, which learn about these methods during their studies, also use them much more frequently in later school life. This supports again the saying of Confucius and shows that his quote does not only reflect learning in young ages, but also applies to adults.

Duit and Treagust (2012) criticize the low subject-specific knowledge of teachers, but especially also their unwillingness to apply constructivistic methods like conceptual change. Also in this respect this thesis is a valuable contribution to the education of teachers. The conception that something water-repellent like the lotus leaf needs to have a smooth surface, was present in 71% of the students. By using this model organism we could easily address a widely distributed wrong conception, by means of showing the effects with hands-on elements and some oral impulses. It only needs some models and a few easy experiments and one can falsify some students' conceptions (Heyne & Kubisch, in press). This allows to inspire a better comprehension of natural scientific working, which apparently is often absent in students and teachers (Duit & Treagust, 2012). So, in some cases the students' conceptions can be assessed rapidly. Thus, the method of conceptual change can be introduced to the university students in a simple way, which certainly could be deepened.

4. Future prospects

The research on education at out-of-school learning settings like the botanical garden should be intensified. Firstly, this is necessary to allow for a better education of the personnel working there and improvements of their education programs. Secondly, it is important to evaluate the contributions of botanical gardens to the education in school. I do not know of any quantitative study regarding the latter point. Such a study would require to be performed over the whole country and would certainly prove helpful in potential future discussions on the usefulness of botanical gardens. It would also be helpful to further investigate the emotions of students in botanical gardens in rather general approaches, not only focusing on one topic or instruction. Attitudes of students towards botany, or conservation, and possible ways of influencing these, should be tested in events over several days, as demanded by Sellman and Bogner (2013) and Drissner et al. (2010).

From my work with the school classes I also know that there are alternative conceptions on carnivorous plants. These could also easily be assessed at the out-of-school learning setting. One could, for example, show *Nepenthes spec.* or *Sarracenia spec.* individuals, where most students will immediately say that certainly the lid of these plants will close to catch insects. There are much more false conceptions of students about carnivorous plants, which would offer good opportunities for a conceptual change study in the botanical garden.

With regard to conceptual change we also raised a question, which should definitely not be forgotten. What happens to students already having a correct conception, if they get confronted with the wrong alternatives? Will they be confused and rather adopt the wrong concepts? Or are their own conceptions already so robust that they cannot be changed? This might often be the case in everyday school life, also if the teacher might have some misconceptions on his / her own, and transfer them to the students. In my opinion this definitely requires additional research, as it is fairly likely that in every class there might be at least one student, which already has a scientific conception of a given topic.

Unfortunately, my study on concept mapping was not very deep and qualitative. Thus, with more students and the treatments mentioned above, one could certainly achieve very detailed and robust findings. Regarding concept mapping one could also additionally try to answer the question, whether this method differs in its success, if it is conducted in the botanical garden, compared to the school.

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APPENDIX

1. WORKBOOK OF THE GUIDED WORKSTATIONS

Fachgruppe
Didaktik
Biologie

Pflanzen und Wasser

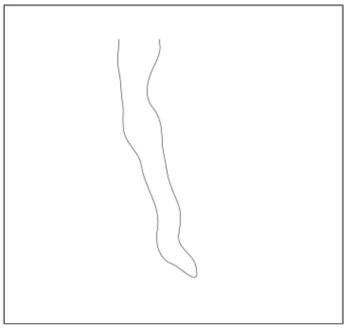
Dieses Laufheft gehört:

____

1

1. Haben Wurzeln Haare?

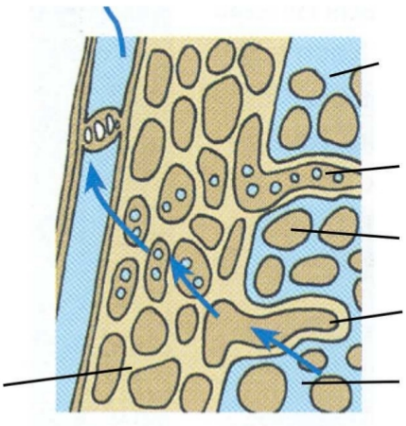
1.1 Betrachte mit der Lupe die Wurzel!
Vervollständige die Zeichnung der Wurzel!



1.2 Worum handelt es sich bei den fädigen Strukturen?

☐ Wurzelhaare ☐ Pilze

1.3 Beschrifte dazu Abbildung 1!
Abbildung 1:



1.4 Wofür benötigt die Pflanze die Wurzelhaare?
1. ________________________________
2. ________________________________

1.5 Warum fließt das Wasser in die Wurzel?
____
____

2

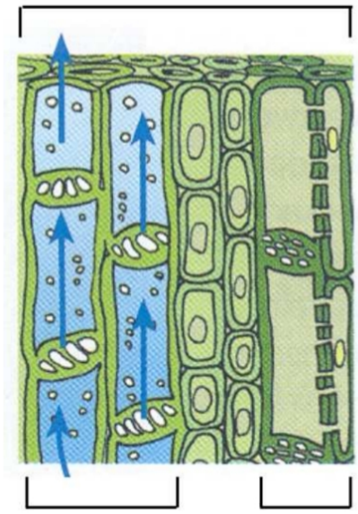
2. Wie kommt das Wasser in die Wipfel I?

2.1 Was sind die blau gefärbten Stränge in dem Staudensellerie?

☐ Wasserbündel ☐ Sprossseile ☐ Leitbündel

2.2 Beschrifte dazu Abbildung 2!

Abbildung 2:



2.3 Fülle den Lückentext aus!

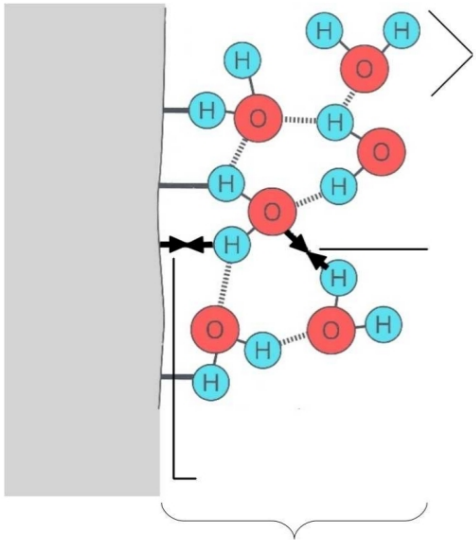
Leitbündel sind in Landpflanzen nicht nur im Stängel, sondern auch in ______________ (ttlbäenr), ______________ (lübent) und der ________________ (urzelw) vorhanden.

Die Leitbündel teilen sich in zwei Zellarten auf, die toten nennt man X _ l _ _ und die lebenden Ph _ _ _ _. Im Xylem wird nicht nur Wasser transportiert, sondern auch gelöste Teilchen, die die Pflanze zur E _ nähru _ g braucht. Das Phloem in den Leitbündeln transportiert Z _ cker von den Blä _ _ er_ in die Wurzel und die F _ ü _ _ te.

3

2.4 Beschrifte dazu Abbildung 3!

Abbildung 3:



2.5 Welche Form des Xylems ist für den Wassertransport am günstigsten?

☐ Rund und ein Durchmesser von 0,5mm.

☐ Rund und ein Durchmesser von 5mm.

2.6 Fülle den Lückentext aus!

Tinte ist Farbe auf der Basis von _ _ ss _ r. Der Staudensellerie kann deshalb die Farbe im X _ l _ _ transportieren.
Möglich ist das, weil die einzelnen Wasser _ ol _ kü _ e miteinander v_ _ bu _ _en sind. Moleküle in einer Phase ziehen sich ge _ ensei _ _ g an. Das nennt man K _ h _ s _ on (v. lat. *cohaerere* „zusammenhängen"). Andererseits werden die Wassermoleküle auch von der Ze _ _ w _ n _ der Pflanze, also zwischen 2 Phasen, _ _ gezo _ en. Das nennt man A _ h _ s _ on (v. lat. *adhaerere* „anheften").
Aufgrund dieser beiden K _ _ ft _ kann das Wasser in der Pflanze entgegen der S _ h _ e_ kra _ t fließen.

4

3. Wie kommt das Wasser in die Wipfel II?

3.1 Bei diesem Versuch baust du durch dein Pusten einen Druck auf.
Welchen?

☐ Unterdruck ☐ Überdruck

3.2 Wie heißt diese Kraft?

☐ Transpirationssog ☐ Wurzeldruck

3.3 Stelle dir nun vor (nicht durchführen!!!) du würdest am anderen Ende (oben an der Pflanze) des Stückes ziehen.
Welchen Druck würdest du dabei ausüben?

☐ Unterdruck ☐ Überdruck

Wie und wo dieser Unterdruck in der Pflanze entsteht lernst du an der nächsten Führungsstation **4**. Diesen Unterdruck nennt man bei Pflanzen **Transpirationssog**.

3.4 Was ist die Folge von diesem Über- und Unterdruck?

____

5

4. Wenn der Basilikum „schwitzt" ...

4.1 Wie nennt man das „schwitzen" bei Pflanzen?

☐ Translokation ☐ Transpiration

4.2 Wie nennt man die Strukturen im Blatt, über die dieser Vorgang funktioniert?

☐ Belüftungszellen. ☐ Spaltöffnungen.

4.3 Welcher Prozess erfolgt noch über diese Strukturen?

☐ Gasaustausch. ☐ Photosynthese.

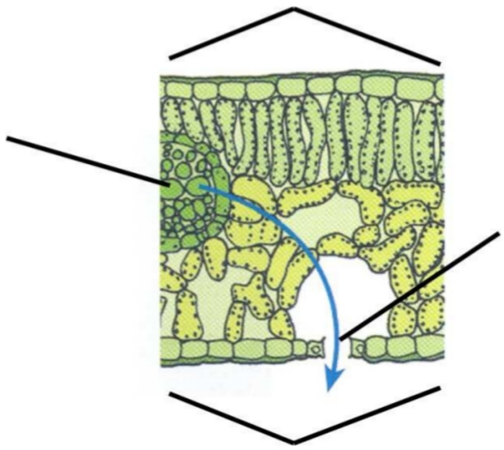
4.4 Warum sind diese Strukturen meist auf der Blatt________seite?

____

____

4.5 Beschrifte dazu Abbildung 4!

Abbildung 4:



4.6 Wie heißt die Kraft, die bei der Transpiration entsteht?

☐ Transpirationssog ☐ Wurzeldruck

4.7 Was hat diese Kraft für die Pflanze zur Folge?

____

____

6

5. Sukkulenz – wie die Aloe vera in der Wüste überlebt?

5.1 Wie dick sind die jeweiligen Blätter circa?

Blatt	Dicke
Breitwegerich	__________mm
Aloe vera	__________mm

5.2 Welchem der Blätter ordnest du welches Klimadiagramm zu?

Breitwegerich:

☐ **A** ☐ **B**

Aloe vera:

☐ **A** ☐ **B**

5.3 Warum?

____

____

5.4 Wo ist …

… Ort **A**:________________________

und

… Ort **B**:________________________

5.5 Was bedeutet nun Sukkulenz?

____

____

5.6 Suche eine Pflanze im Gewächshaus, die das Wasser im Stamm speichert und eine andere als die Aloe vera, die Wasser in den Blättern speichert.

Notiere dir ihre Namen!

1. _______________________________
2. _______________________________

6. Wie schwimmt es sich am besten?

6.1

a. Was passiert, wenn durch den Stängel gepustet wird?

____

b. Was passiert, wenn das Blatt mit der Oberseite nach unten gedreht wird und in den Stängel gepustet wird?

____

c. Wie erklärt sich deine Beobachtung?

1.____

2.____

6.2 Warum ist es für die Seerose wichtig, dass der Stängel biegsam ist?

____

____

6.3

a. Bleiben die Blätter nach dem untertauchen unter Wasser?
Prüfe es!

☐ Ja ☐ Nein

b. Was ist es was die Blätter oben schwimmen lässt?

☐ Mit Luft gefüllte Zellen. ☐ Mit Fett gefüllte Zellen.

2. Workbook of the self-determined workstations with correct answers

Fachgruppe Didaktik Biologie

Pflanzen und Wasser

Lösungsheft

1

Erläuterungen zum Bearbeiten der Stationen

Dieses Arbeitsheft wird dich in der nächsten Stunde begleiten. Hier findest du Aufgaben zu den einzelnen Stationen, die du mit deiner Gruppe lösen darfst. Du kannst hier deine Ergebnisse festhalten. Außerdem sollt ihr über die Aufgaben, Ergebnisse und Überlegungen diskutieren.

Wichtiges:

Stationen: In welcher Reihenfolge du die Stationen bearbeitest ist dir überlassen. Die Station wird immer vollständig bearbeitet und danach so verlassen, wie du sie vorgefunden hast! Es gibt insgesamt sechs Stationen und eine Zusatzstation für Schnelle. An der Blütenpflanze oben rechts zeichnest du an jeder Station ein, um welchen Teil der Pflanze es gerade geht. An einigen Stationen helfen dir Infoblätter in Boxen bei der Beantwortung der Fragen.

Laufzettel: Auf der zweiten Seite des Arbeitsheftes findest du einen „Laufzettel“ auf dem du die vollständig bearbeiteten Stationen abhakst!

Lösungsheft: Das Lösungsheft sollst du beim Betreuer nach jeder vollständig bearbeiteten Station einsehen. Sei ehrlich und korrigiere mit einem anders farbigem Stift deine Ergebnisse und ergänze!

Symbole:

 Info/Lies

 Bearbeite

 Vermute

 Zeichne

 Fühle

 Betrachte

 Experimentiere

Laufzettel

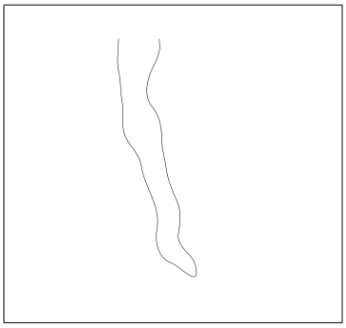
Bitte hake nach jeder vollständig bearbeiteten Station ab!
In der letzten Spalte notierst du bitte wie gut dir die Station gefallen hat, mithilfe von Schulnoten von 1-6!

Station	Titel	Erledigt	Note
1	Haben Wurzeln Haare?		
2	Wie kommt das Wasser in die Wipfel I?		
3	Wie kommt das Wasser in die Wipfel II?		
4	Wenn der Basilikum „schwitzt“ ...		
5	Sukkulenz – wie die Aloe vera in der Wüste überlebt		
6	Wie schwimmt es sich am besten?		
Zusatz für Schnelle	Das Geheimnis der Tillandsien		

Möchtest du sonst noch etwas los werden, kannst du es hier notieren:

Station 1: Haben Wurzeln Haare?

1.1 Vervollständige die Zeichnung der Wurzel?



1.2 Worum handelt es sich bei den fädigen Strukturen?

☒ Wurzelhaare ☐ Pilze

1.3 Beantworte folgende Fragen mithilfe der Infoblätter!
Wofür benötigt die Pflanze diese fädigen Strukturen? (Informationsblatt I)

1. Wasseraufnahme
2. Oberflächenvergrößerung

Warum fließt das Wasser in die Wurzel? (Informationsblatt II)
Nach einem Regen ist im Boden viel Wasser. In der Wurzel weniger. Wasser strömt vom Ort hoher Konzentration zum Ort niedriger Konzentration. Deshalb fließt das Wasser vom Boden durch die Zellwand in die Wurzel.

Station 2: Wie kommt das Wasser in die Wipfel I?

2.1 Wie nennt man diese Stränge? Was vermutest du?

- [ ] Sprossseile
- [x] Leitbündel

2.2 Fülle die Lücken nun mithilfe des Informationsblattes I und Abbildung 1:

Leitbündel sind in Landpflanzen nicht nur im Stängel, sondern auch in Blättern, Blüten und der Wurzel vorhanden.
Die Leitbündel teilen sich in zwei Zellarten auf, die toten nennt man Xylem und die lebenden Phloem. Im Xylem wird nicht nur Wasser transportiert, sondern auch gelöste Teilchen, die die Pflanze zur Ernährung braucht. Das Phloem in den Leitbündeln transportiert Zucker von den Blättern in die Wurzel und Früchte.

2.3 Wie das mit dem Wassertransport funktioniert erklärt dir der folgende Lückentext. Mithilfe der Abbildung 2 auf Informationsblatt II kannst du die Lücken sicher ausfüllen.

Tinte ist Farbe auf der Basis von Wasser. Der Staudensellerie kann deshalb die Farbe im Xylem transportieren.
Möglich ist das, weil die einzelnen Wasser Moleküle miteinander verbunden sind, so ziehen sich die Moleküle in einer Phase gegenseitig an. Das nennt man Kohäsion (v. lat. *cohaerere* „zusammenhängen"). Andererseits werden die Wassermoleküle auch von der Zellwand der Pflanze, also zwischen 2 Phasen, angezogen. Das nennt man dann Adhäsion (v. lat. *adhaerere* „anheften"). Aufgrund dieser beiden Kräfte kann das Wasser in der Pflanze entgegen der Schwerkraft fließen.

3

2.4 Zeichne die Transportrichtung in der Pflanze anhand von Pfeilen hinter die Begriffe!

Phloem Xylem

2.5 Betrachte die mit Wasser gefüllten Messzylinder an der Station! In beiden befindet sich dieselbe Menge an Wasser: 10 ml.
Welche Form der Leitbündel lässt das Wasser höher steigen?

☒ Rund und ein Durchmesser von 0,5mm.

☐ Rund und ein Durchmesser von 5mm.

Station 3:
Wie kommt das Wasser in die Wipfel II?

3.1 Nimm dir ein Stück Waldrebe und betrachte den Querschnitt! Was siehst du?
Große und kleine Poren/Löcher.

3.2 Nun hältst du dieses Ende in das Wasser mit Spülmittel (ist vorbereitet) und pustest am anderen Ende hinein!

Was vermutest du wird passieren?

Die Luft kommt am anderen Ende im Wasser in Form von Blasen wieder raus.

Was beobachtest du?

Es entstehen Seifenblasen. Es blubbert, wie bei einem Strohhalm.

3.3 Welche Art von Druck baust du durch dein Pusten auf.

☐ Unterdruck ☒ Überdruck

Dieser Überdruck wirkt auf die Wurzel und wird auch als Wurzeldruck bezeichnet.

3.4 Gedankenexperiment:
Stelle dir nun vor (nicht durchführen!!!) du würdest am anderen Ende (oben an der Pflanze) des Stückes saugen.
Welchen Druck würdest du dabei ausüben?

☒ Unterdruck ☐ Überdruck

Solch ein Unterdruck entsteht in den Blättern der Pflanze, dort nennt man diese Kraft auch Transpirationssog.

3.5 Was ist die Folge von diesem Über- und Unterdruck?

Das Wasser im Stängel der Pflanze steigt bis zu den Blättern.

Station 4: Wenn der Basilikum „schwitzt“ ...

4.1 Betrachte die Folie am Basilikum.
Was kannst du erkennen?
Man kann kleine Wassertröpfchen erkennen.

4.2 Nimm die Folie vorsichtig von den Blättern des Basilikums.

Was spürst du?
Es fühlt sich nass an.

4.3 Für die Beantwortung der nächsten Fragen lies den Text und betrachte das Bild auf Informationsblatt I!

Wie nennt man diesen Vorgang bei Pflanzen?

- [ ] Translokation
- [x] Transpiration

Wie nennt man die Strukturen über die dieser Vorgang funktioniert?

- [ ] Belüftungszellen.
- [x] Spaltöffnungen.

Welcher Prozess erfolgt noch über die Spaltöffnungen?

- [x] Gasaustausch.
- [ ] Photosynthese.

4.4 Hier musst du selbst überlegen. Warum sind diese Strukturen meist auf der Blattunterseite?

Wären die Spaltöffnungen auf der Blattoberseite, würde die Pflanze an sonnigen Tagen viel zu viel Wasser durch Transpiration verlieren.

4.5 Lies Informationsblatt II und beantworte!
Wie heißt die Kraft, die bei der Transpiration entsteht?

- [x] Transpirationssog
- [ ] Wurzeldruck

Was hat diese Kraft für die Pflanze zur Folge?
Dass das Wasser vom Stängel in die Blätter fließt. Von den Blättern bewegen sie die Moleküle weiter an die Luft.

Station 5: Sukkulenz – wie der Kaktus in der Wüste überlebt?

5.1 An der Station findest du ein Breitwegerichblatt (typisch für unsere Gegend) und ein Aloe vera-Blatt (wächst im Gewächshaus). Miss die Dicke der zwei Blätter (in den Boxen) genau aus und notiere sie dir in der Tabelle.

Blatt	Dicke	Klimadiagramm
Breitwegerichblatt	ca. 0,5 – 1 mm	A
Aloe vera	ca. 15 - 35 mm	B

5.2 Versuche nun aus einem Breitwegerichblatt (Box 1) und einem Stück der Aloe vera (Box 2) das Wasser heraus zu pressen.

Was stellst du fest?

Aloe vera: Beinhaltet viel Wasser, so dass man einen Tropfen raus pressen kann.

Breitwegerich: Beinhaltet wenig Wasser, so dass man keinen Tropfen raus pressen kann.

5.3 Welches ist nun das sukkulente Blatt?

Das Aloe vera – Blatt.

5.4.1 Ordne die Blätter den Klimadiagrammen an der Station zu!

Trage deine Entscheidung in die Tabelle oben und begründe hier!

In Ort A regnet es das ganze Jahr über in jedem Monat fast 60 mm. Es steht also immer genug Wasser für die Pflanzen zur Verfügung. Sie müssen kein Wasser in ihren Blättern speichern, so wie der Breitwegerich. In Ort B jedoch regnet es sehr wenig und im Sommer gar nicht. Es ist viel wärmer als in A. Die Pflanzen müssen sich an diese Trockenheit anpassen. Die Aloe vera speichert das Wasser deshalb in ihren Blättern.

5.4.2 Wie viele mm regnet es durchschnittlich in Ort **A** im Juli?

56 – 58 mm

5.4.3 Wie viele °C hat es durchschnittlich in Ort **B** im Juni?

Circa 36°C.

5.4.4 Was meinst du, wo ist …

… Ort **A**? Deutschland, genauer Würzburg

… Ort **B**? Arabische Halbinsel, Kaisumah

5.5 Es gibt auch sukkulente Pflanzen die Wasser in ihrem Stamm oder ihrer Wurzel speichern, z. Bsp. der Kaktus.

7

Station 6: Wie schwimmt es sich am besten?

6.1 Nimm dir nun das Ende des Stängels und betrachte es mit der Lupe.

6.1.1 Was fällt dir auf?
Beschreibe:

Im Stängel sieht man große Poren mit Luft gefüllt.

6.1.2 Und zeichne diesen Teil der Pflanze!

6.2.2 Nimm nun das Ende des Stängels und puste kräftig hinein, halte dabei das Blatt unter Wasser!

Vermute was passieren wird?

Es steigen Blasen von der Oberseite des Blattes auf.

Was beobachtest du?

Es steigen Blasen von der Oberseite des Blattes auf.

6.2.3 Drehe das Blatt mit der Unterseite nach oben! Was passiert jetzt, wenn du in den Stängel pustest?

Auf der Unterseite kommen keine Bläschen aus dem Blatt (wenn doch ist das Blatt an dieser Stelle eingerissen!).

Wo befinden sich demzufolge bei dieser Pflanze die Spaltöffnungen?

☒ Oben ☐ Unten

Der Stängel der Seerose ist also hohl. Dies ist auch der Grund dafür, dass der Spross sehr biegsam ist, wie dir vielleicht schon aufgefallen ist.

6.3 Überlege selbst: Warum ist es für die Seerose wichtig, dass der Stängel biegsam ist?

Bei Wind oder durch vorbei schwimmende Tiere wird das Wasser verwirbelt und in Bewegung gesetzt. Durch den biegsamen Stängel kann sich die Seerose mit bewegen und reißt nicht ab.

6.4.1 Bleiben die Blätter nach dem untertauchen unter Wasser? Prüfe es!

☐ Ja ☒ Nein

6.4.2 Was ist es was die Blätter schwimmen lässt? Auch hier hilft dir die Abbildung an der Station.

☒ Mit Luft gefüllte Zellen. ☐ Mit Fett gefüllte Zellen.

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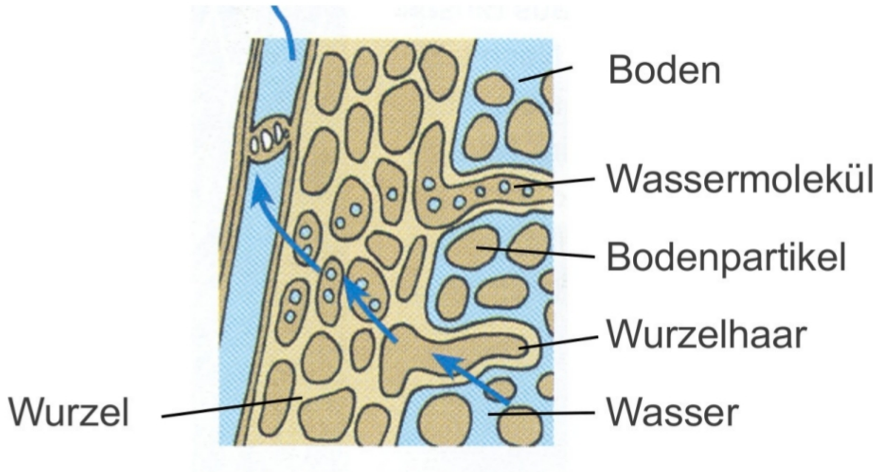
3. WORKSTATIONS MATERIAL

Station 1: Informationsblatt I

Die 1. Abbildung zeigt dir mittels der blauen Pfeile den Weg des Wassers vom Boden in die Wurzel:

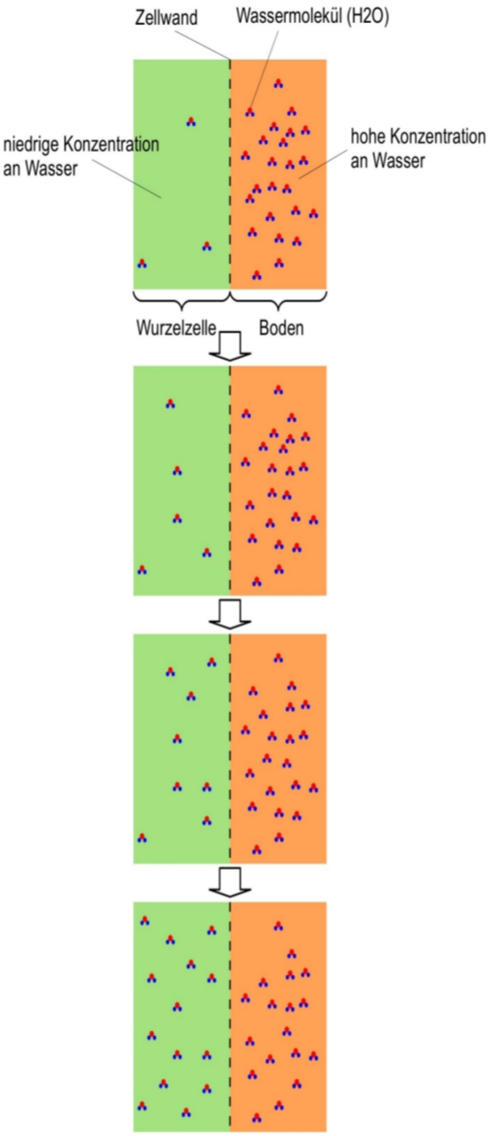
Abbildung 1



Die Wurzelhaare der Pflanze bestehen aus einer einzigen Zelle. Diese Wurzelhaare nehmen Wasser, aus dem Boden, auf. Eine Wurzel besitzt sehr viele solcher Wurzelhaare und kann somit mehr Wasser aus dem Boden aufnehmen. Die Wurzelhaare vergrößern also die Oberfläche der Wurzel.

Station 1: Informationsblatt II

Abbildung 2



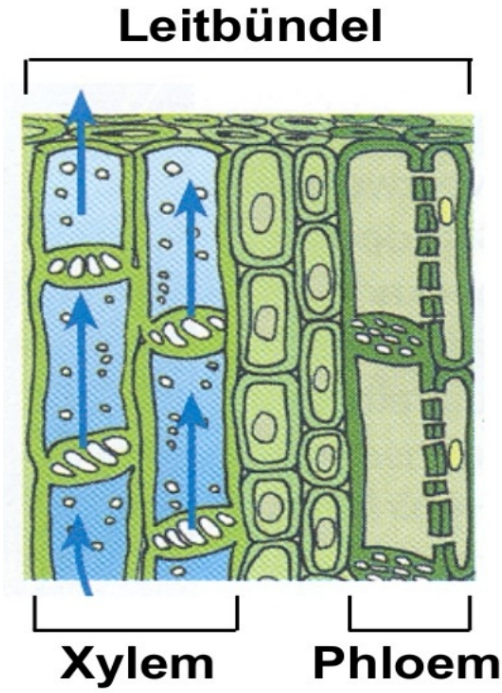
Dass Pflanzen Wasser aufnehmen können, liegt daran, dass sich im Boden viel Wasser befindet, in den Wurzelhaarzellen jedoch nicht (Abbildung **2 oben**).
Alle Gase und Flüssigkeiten auf der Erde, so auch Wasser, verteilen sich immer gleich. Das heißt also, dass das Wasser vom Ort **hoher** Konzentration zum Ort **niedriger** Konzentration fließt, bis sich ein Gleichgewicht zwischen den Orten einstellt.
Die Zellwand der Wurzelhaare ist wasserdurchlässig, so kann Wasser einströmen (Abbildung **2 mittig**). In der Wurzel wird das Wasser aber weiter zum Spross transportiert, so dass es nie zu einer gleichmäßigen Verteilung kommt (Abbildung **2 unten)**. Ist im Boden genügend Wasser strömt es ständig in die Wurzelhaare nach.

•

Station 2: Informationsblatt I

Die blauen Pfeile zeigen dir den Weg des Wassers durch den Stängel der Pflanze. Im Stängel und den Blättern einer Pflanze, wie beim Staudensellerie, befinden sich meist mehrere Leitbündel.

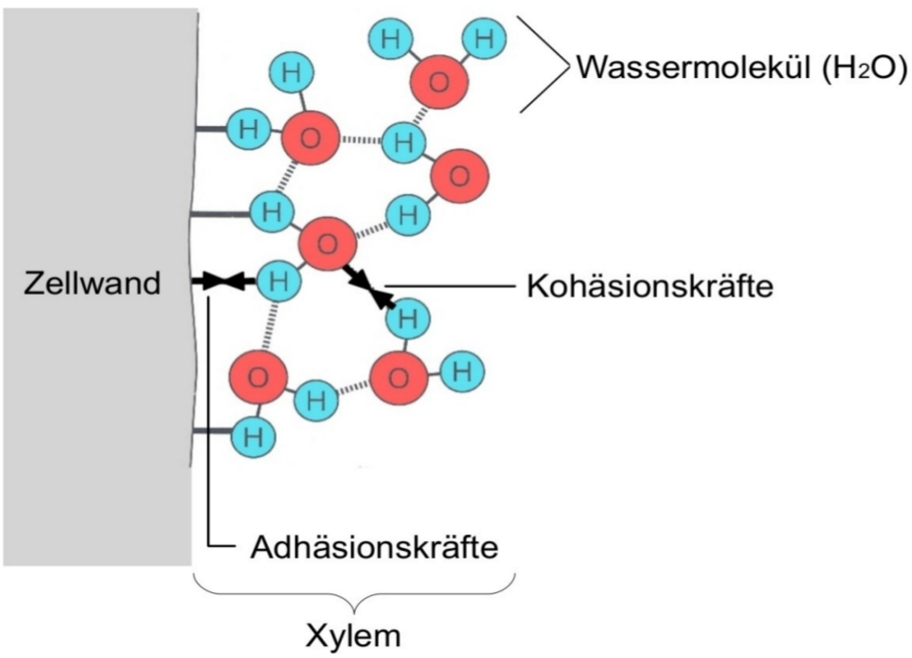
Abbildung 1



Station 2: Informationsblatt II

Die Abbildung 2 zeigt Wassermoleküle im sogenannten Xylem (siehe Abbildung I an dieser Station), im Leitbündel eines Sprosses.

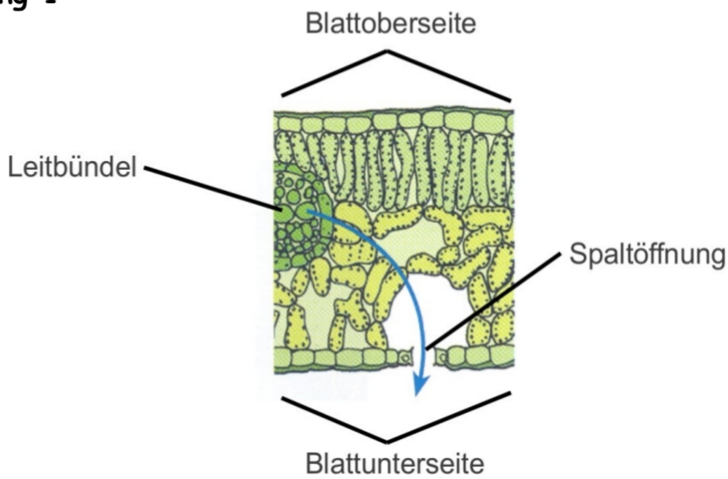
Abbildung 2



Station 4: Informationsblatt I

Abbildung 1 zeigt den Querschnitt durch das Laubblatt einer Landpflanze. Der blaue Pfeil zeigt an, dass das Wasser aus den Leitbündeln im Blatt nach außen abgegeben wird.

Abbildung 1

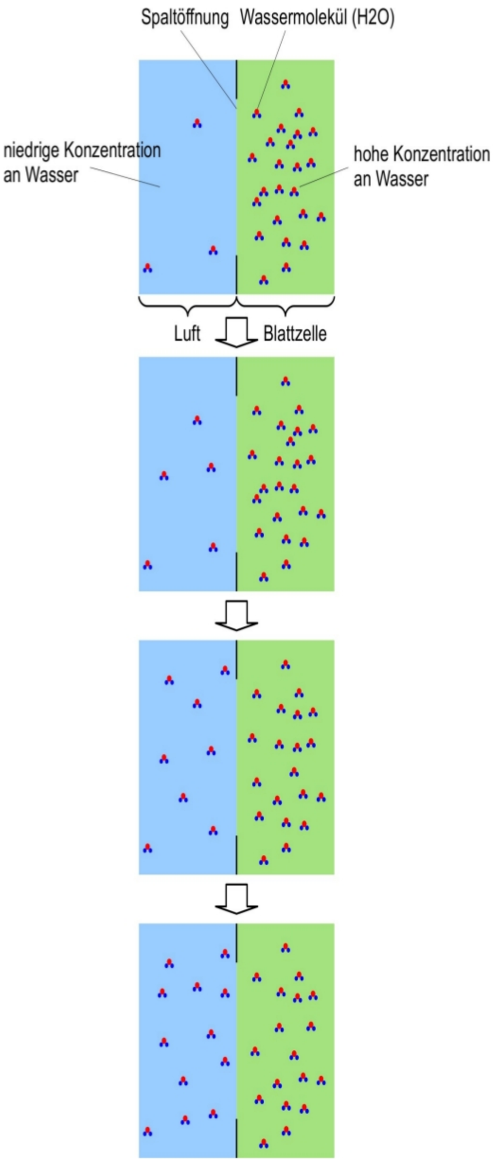


Die Wasserabgabe bei Pflanzen über die Blätter bezeichnet man als Transpiration. Das Wasser wird über kleine Öffnungen im Blatt, den Spaltöffnungen, abgegeben. Neben der Wasserabgabe erfolgt über die Spaltöffnungen aber auch der Gasaustausch. Die Pflanzen geben Sauerstoff an die Umgebung ab und nehmen Kohlendioxid auf.

Bei Landpflanzen befinden sich die Spaltöffnungen meist an der Blattunterseite. Die Transpiration führt bei Sonnenschein und Wind zur Kühlung der Blätter. Wie die Transpiration genau abläuft erfährst du auf Informationsblatt II an dieser Station.

Station 4: Informationsblatt II

Abbildung 2



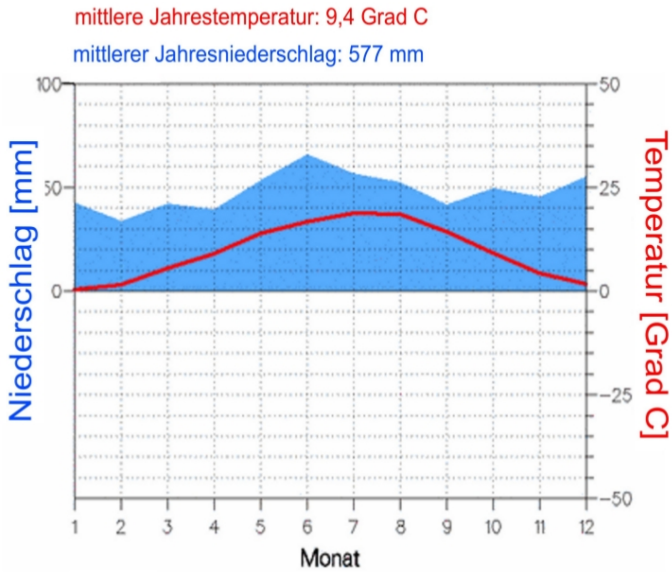
Wasser strömt vom Ort hoher Konzentration zum Ort niedriger Konzentration.
Im Blatt des Basilikums ist viel Wasser – in der Luft dagegen weniger (Abbildung **2 oben**).
Daher bewegen sich die Wassermoleküle über die Spaltöffnungen aus dem Blatt an die Luft (Abbildung **2 Mitte**).

Durch den Wind werden diese Wassermoleküle verteilt und es strömen immer neue aus dem Blatt nach. Im Blatt entsteht dabei ein Unterdruck, der sogenannte Transpirationssog.
Dabei strömt dass Wasser immer weiter aus dem Spross in die Blätter nach. Somit strömt auch das Wasser aus der Wurzel in den Spross.
Das Wasser in der Pflanze steigt.

Durch das Nachströmen des Wassers im Leitbündel (Abbildung **1**) und durch den Wind kommt es nie zur Gleichverteilung der Moleküle zwischen außen und innen (Abbildung **2 unten**).

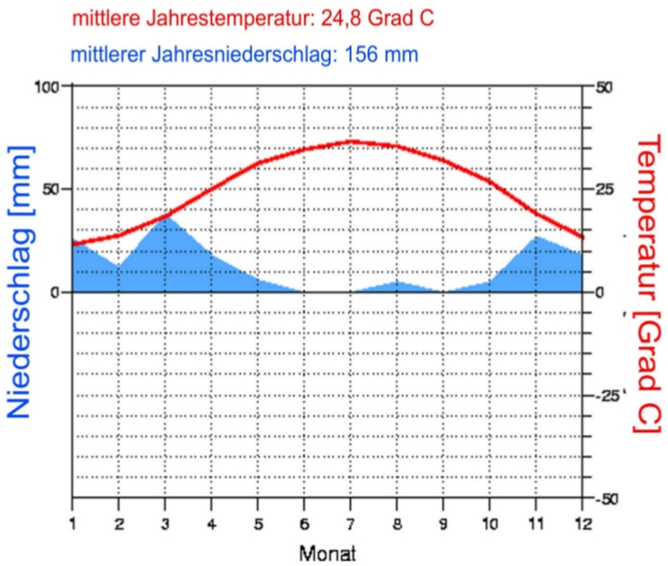
Station 5: Informationsblatt I

Ort A



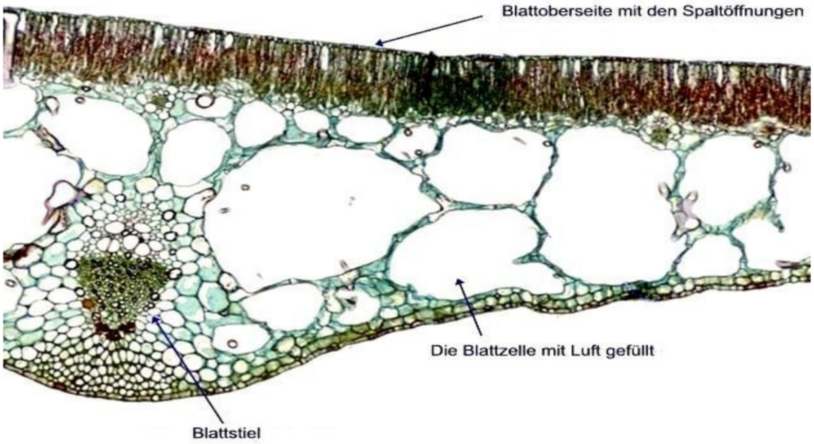
In dem Ort **A** regnet es im Jahr auf einer Fläche von 10x10 cm (siehe grünes Quadrat) durchschnittlich so viel Wasser wie in **drei (5,5 l)** Kolben passen. In dem Ort **B** regnet es im Jahr auf 10x10 cm (siehe grünes Quadrat) durchschnittlich so viel Wasser wie in **einen (1,5 l)** Kolben passt.

Ort B



Station 6: Informationsblatt I

Querschnitt durch das Blatt einer Seerose im Mikroskop.



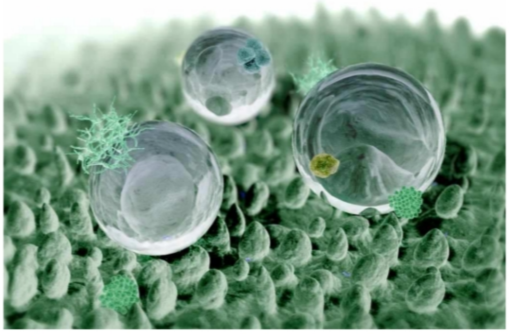
4. Workbook of the lotus effect instruction

Fachgruppe Didaktik Biologie

Der Lotuseffekt oder warum die Regenjacke wasserabweisend ist?

Dieses Experimentierheft gehört:

____



Experiment 1: Was bedeutet Benetzbarkeit von Oberflächen?

Flüssigkeitstropfen verhalten sich auf rauen Oberflächen anders als auf glatten. Der Tropfen kann kugelig oder flach sein. Ist der Tropfen auf einer Oberfläche kugelig so ist sie schlecht benetzbar. Ist der Tropfen flach, ist die Oberfläche gut benetzbar. In der Natur spielt das für Laubblätter eine große Rolle.

1a: Benetzbarkeit von Laubblättern

Materialien:
Wachsschale mit befestigten Blattteilen (Kapuzinerkresse - rechts und Buche - links) und Geo-Dreieck, Pipette, Wasser, Pinzette, Binokular

Durchführung:
1a) 1.
– vorsichtig je einen Tropfen Wasser auf die beiden Blätter geben
– schau dir die Tropfen genau an (evtl. auch unter dem Binokular)
Was siehst du im Vergleich der Tropfen?

Beobachtung:
Buche:____
Kapuzinerkresse:____________________________________

1a) 2.
– vorsichtig je einen Tropfen Wasser auf die Blätter in der Wachsschale geben
– nimm die Pinzette und hebe ein Blatt nach dem anderen **vorsichtig** am Rand an
– stoppe, wenn der Tropfen weg rollt und lies den Winkel ab

Zuvor gibst du eine Schätzung ab!
Vermutung:
Buche:____
Kapuzinerkresse:____________________________________

Deine Messergebnisse trägst du in die Tabelle auf **Seite 3** ein! Wiederhole deine Messung zur Überprüfung!

2

Ergebnis:

Blatt	1. Messung	2. Messung
Buche	________	_________
Kapuzinerkresse	________	_________

Erkläre und deute deine Ergebnisse:

____
____
____

Welches Blatt war „besser benetzbar"?

_

1b: Den Lotuseffekt selber machen

Materialien:
Glasplättchen, Pipette, Wasser, Feuerzeug, Tuch

Durchführung:
1b) 1
- tropfe einen Tropfen Wasser aus ca. 5 cm Höhe auf das Glas

Vermute was passiert:
____

Was **beobachtest** du tatsächlich:
____

1b) 2
- trockne das Glasplättchen gut ab
- auf derselben Seite erwärmst du das Glas **vorsichtig gleichmäßig,** bis es eingerußt ist
- nun lässt du einen Tropfen Wasser aus ca. 5 cm Höhe auf das verrußte Glas fallen

Was **vermutest** du wird mit dem Tropfen passieren?
____

Beobachtung:
____

Erkläre und deute deine Ergebnisse:
____
____
____

Experiment 2: Zerstörung der Benetzbarkeit?

Die Eigenschaften der Blattoberflächen lassen sich beeinflussen. Die Folgen solcher Beeinflussung für die Benetzbarkeit der Laubblätter kannst du jetzt überprüfen.

Materialien:
Wachsschale mit befestigten Blattteilen (Kapuzinerkresse - rechts und Buche - links) und Geo-Dreieck, Pipette, Wasser, Wattestäbchen, Pinzette, Binokular

Durchführung:
2.1
- reibe auf beiden Blättern eine Stelle mit dem Wattestäbchen **vorsichtig** ab
- tropfe dann einen Tropfen auf diese Stellen

Was wird mit den Tropfen passieren?
Vermute!
Buche:____
Kapuzinerkresse:____

Was **beobachtest** du im Vergleich der Tropfen?
Buche:____
Kapuzinerkresse:____

2.2
- nimm nun die Pinzette und hebe das Blatt **vorsichtig** am Rand an
- stoppe, wenn der Tropfen weg rollt und lies den Winkel ab

Zuvor gibst du wieder eine Schätzung ab!
Vermutung:
Buche:____
Kapuzinerkresse:____

Deine Messergebnisse trägst du in die Tabelle auf **Seite 6** ein! Wiederhole deine Messung zur Überprüfung!

Ergebnis:

Blatt	1. Messung	2. Messung
Buche	__________	___________
Kapuzinerkresse	__________	___________

Erkläre und deute deine Ergebnisse:

____

____

6

Experiment 3: Selbstreinigende Blätter

Sind Blätter mit dem Lotuseffekt wirklich selbstreinigend? Überprüfe es!
Wichtig: Bevor du mit diesem Versuch startest, nimm die gebrauchten Blätter aus der Schale und ersetze sie durch neue bereits zugeschnittene Blattteile. Das Geo-Dreieck benötigst du nun nicht mehr.

Materialien:
Neue Blätter, Wachsschale, Pipette, Wasser, Erde, Binokular

Durchführung:
3.1
- gib auf beide Blätter eine Prise Erde
- dann tropfst du einen oder mehrere Tropfen Wasser auf die Erde

Was siehst du?
Beobachtung:
Buche:____
Kapuzinerkresse:______________________________________

3.2
- lass die Tropfen nun von den Blättern fließen

Beobachtung:
Buche:____
Kapuzinerkresse:______________________________________

Erkläre und deute deine Beobachtung:
____
____
____

Welches Blatt erfüllt die Bedingungen für den Lotuseffekt?

☐ Buche ☐ Kapuzinerkresse

7

Experiment 4: Zusatzversuch für Schnelle

4.1
Was meinst du, funktioniert der Lotuseffekt auch mit Honig?
Vermutung:
-
4.2
Gib einfach ein paar Tropfen Honig auf die vollständigen Blätter beim Betreuer!
Beobachtung:
-
4.3
Warum sollte der Lotuseffekt auch mit solchen zähflüssigen Substanzen funktionieren?
Erklärung:
____
____

Abschließend möchte ich nun von dir wissen welche Eigenschaften eine Regenjacke haben muss, damit sie wasser- und schmutzabweisend ist?

1.______________________________
2.______________________________

8

5. MULTIPLE-CHOICE-QUESTIONNAIRE

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

Fakultät für Biologie

Fachgruppe Didaktik Biologie

Fachgruppe Didaktik Biologie - Wittelsbacherplatz 1 - 97074 Würzburg

Liebe Schüler, liebe Schülerinnen,

um eure Anonymität zu wahren und trotzdem im Nachhinein die Fragebögen einander zuordnen zu können, füllt ihr bitte unten stehenden Kasten aus, so dass ein persönlicher Code entsteht.

Dein Geschlecht:	☐ männlich	☐ weiblich
Dein Alter:	______________________	
Dein Geburtsmonat:	______________________	Beispiel: Mai = 05
Der 1. und 2. Buchstabe des Vornamens deiner Mutter:	______________________	Beispiel: Frederike= Fr
Deine Hausnummer:	______________________	

Hinweise:

- Bitte lies die Fragen **genau** durch bevor du sie beantwortest.

- Es gibt immer nur **eine richtige Antwort**.

- Wenn du dich mal vertan hast, male das Kästchen komplett aus und kreuze einfach ein neues an.

- Deine Antworten werden nicht benotet und du bleibst anonym.

- Beispiele stehen in Klammern, damit du weißt was gemeint ist.

<u>Fragen zu deinem Wissen über „Pflanzen und Wasser“</u>

1. Welcher Teil der Pflanze nimmt in der Regel Wasser auf?

- ☐ Stängel
- ☐ Blätter
- ☐ Blüte
- ☐ Wurzel

2. Eine Aufgabe der Wurzelhaare ist...

- ☐ die Zuckerabgabe.
- ☐ die Zuckeraufnahme.
- ☐ die Vergrößerung der Oberfläche.
- ☐ die Verkleinerung der Oberfläche.

3. Wie heißen die Strukturen im Blatt, mit denen Pflanzen Sauerstoff und Wasserdampf abgeben?

- ☐ Schließspalten
- ☐ Dampföffnungen
- ☐ Blattporen
- ☐ Spaltöffnungen

4. Pflanzen leiten Wasser zu den Blättern durch ...

- ☐ Leitbündel in der Frucht.
- ☐ Druckmaschinen im Stamm.
- ☐ Leitbündel in der Wurzel.
- ☐ Leitbündel im Stängel.

5. Der Stängel einer Seerose ist ...

- ☐ innen geschlossen und fest.
- ☐ innen mit Milchsaft gefüllt und biegsam.
- ☐ innen mit Fett gefüllt und biegsam.
- ☐ innen hohl und biegsam.

6. Welche Anpassung haben Wasserpflanzen um schwimmen zu können?

- ☐ Luft
- ☐ Fett
- ☐ Wasser
- ☐ Zucker

7. Pustet man in einen Waldrebenstängel …

- ☐ passiert nichts.
- ☐ bläst sich dieser wie ein Luftballon auf.
- ☐ kommt die Luft am anderen Ende heraus.
- ☐ zieht er sich zusammen.

8. Was beinhaltet Sukkulenz?

- ☐ Wasserundurchlässigkeit
- ☐ Wasserspeicherung
- ☐ Wasserdurchlässigkeit
- ☐ Wasserabgabe

9. Wo müssen Pflanzen viel Wasser speichern?

- ☐ Regenwald
- ☐ Nordpol
- ☐ Wüste
- ☐ Südpol

10. Wassermoleküle …

- ☐ stoßen sich ab.
- ☐ ziehen sich an.
- ☐ neutralisieren sich.
- ☐ machen nichts von allem.

11. Wo speichert die *Aloe vera* Wasser?

- ☐ In der Blüte.
- ☐ Im Stängel.
- ☐ In den Blättern.
- ☐ In der Wurzel.

12. Durch die Transpiration entsteht in den Blättern der Pflanze ein …

- ☐ Schalldruck.
- ☐ Wasserdruck.
- ☐ Überdruck.
- ☐ Unterdruck.

13. Wo befinden sich die Spaltöffnungen bei der Seerose?

- ☐ Sie besitzt keine.
- ☐ An der Blattunterseite.
- ☐ An der Blattoberseite.
- ☐ An den Blatträndern.

14. Wie heißen die Kräfte zwischen gleichen Molekülen in einer Phase?

- ☐ Kooperation.
- ☐ Kohäsion.
- ☐ Adhäsion.
- ☐ Kommunikation.

15. Die Blätter der Lotospflanze waren ein Vorbild für ...

- ☐ Hausanstriche.
- ☐ Segelflieger.
- ☐ Kleber.
- ☐ Roboter.

16. Was ist ein Beispiel für Bionik?

- ☐ Mikroskop.
- ☐ Genmais.
- ☐ Klettverschluss.
- ☐ Photovoltaik.

17. Der Wurzeldruck entsteht durch …

- ☐ die Bodenteilchen.
- ☐ den Druck der Wurzelhaare.
- ☐ die Transpiration.
- ☐ das Fließen des Wassers in die Wurzel.

Fragen zu deinem Wissen über den „Lotuseffekt“

18. Was verstehst du unter dem Lotuseffekt bei Autos?

- ☐ Dass das Wasser von der Scheibe abperlt.
- ☐ Das ist eine Funktion des Motors.
- ☐ Das ist eine Automarke.
- ☐ Dass Wasser den Schmutz vom Lack und den Scheiben abspült.

19. Was glaubst du ist Bionik, wenn du weißt, dass “Bio-” für Biologie und “-nik” für Technik steht?

- ☐ Das ist Technik die man entwickelt hat um biologisch zu forschen (Mikroskop).
- ☐ Das ist, wenn Biologie als Technik verwendet wird (Bierbrauen).
- ☐ Das ist die Technik eines Tieres oder einer Pflanze (Fliegen, Photosynthese).
- ☐ Das ist, wenn der Mensch sich Funktionen von der Natur abschaut, nachbaut und nutzt (Schwimmanzug).

20. Was denkst du, warum durch Regenjacken und Regenschirme kein Wasser auf deine Haut kommt?

- ☐ Weil das Material sehr engmaschig ist und deshalb wasserdicht ist.
- ☐ Weil sie eine glatte Oberfläche, ähnlich wie Plastik besitzen.
- ☐ Weil sie mit einer Chemikalie imprägniert wurden.
- ☐ Weil sie eine raue, wasserabweisende Oberfläche besitzen.

21. Warum ist ein Tropfen Wasser kugelig und nicht quadratisch?

- ☐ Weil die Wassermoleküle sich gegenseitig anziehen.
- ☐ Ein Wassertropfen kann nicht quadratisch sein.
- ☐ Wegen der Erdanziehungskraft.
- ☐ Wegen dem freien Fallen.

22. Wie ist die Oberflächenform eines wasserabweisenden Laubblattes in 1000facher Vergrößerung?

- ☐ netzartig mit strömendem Wasser
- ☐ mit Härchen besetzt
- ☐ rau
- ☐ glatt

23. Was verstehst du unter der Oberflächenspannung?

- ☐ Jemand bringt eine Flüssigkeit auf Spannung.
- ☐ Die Fläche zwischen einer Flüssigkeit und einem Gas.
- ☐ Das ist eine Schicht auf einer Flüssigkeit.
- ☐ Jemand bringt ein Tuch (Bettlagen) auf Spannung.

24. Was ist gemeint, wenn jemand sagt etwas sei schlecht benetzbar?

- ☐ Man hat einen schlechten Empfang (Handy, Internet, Strom).
- ☐ Man kann kein Netz über etwas spannen (z. Bsp. Über einen Teich, Wald...)
- ☐ Wasser perlt gut ab.
- ☐ Wasser perlt schlecht ab.

25. Warum ist es für manche Tiere wichtig, wasserabweisend zu sein?

- ☐ Um fliegen zu können.
- ☐ Damit sie keine Angst haben müssen.
- ☐ Damit sie nicht nass werden.
- ☐ Um schneller schwimmen zu können.

26. Warum ist es für manche Pflanzen wichtig, wasserabweisend zu sein?

- ☐ Damit sie nicht zu viel Wasser aufnehmen.
- ☐ Damit sie nicht abknicken.
- ☐ Damit sie im Wasser nicht ertrinken.
- ☐ Damit das Wasser Schmutz und Krankheitserreger abspült.

27. Wo auf der Erde ist es besonders wichtig, wasserabweisend zu sein?

- ☐ In der Wüste.
- ☐ Im Ozean.
- ☐ Im Regenwald.
- ☐ Am Nordpol und Südpol.

Fragen zu deinen Emotionen und deiner Motivation am heutigen Tag

	Trifft nicht zu	Trifft wenig zu	Trifft schon zu	Trifft voll zu
a) Ich würde die Aktivitäten heute als sehr interessant beschreiben.	☐	☐	☐	☐
b) Ich fand die Aktivitäten langweilig.	☐	☐	☐	☐
c) Ich habe den Tag heute sehr genossen.	☐	☐	☐	☐
d) Ich denke ich war bei den Aktivitäten heute sehr gut.	☐	☐	☐	☐
e) Ich habe heute viel Fleiß in die Aktivitäten investiert.	☐	☐	☐	☐
f) Ich fühlte mich beim ausführen der Aktivitäten heute sehr angespannt.	☐	☐	☐	☐
g) Ich war bereits sehr erfahren mit solchen Aktivitäten.	☐	☐	☐	☐
h) Ich finde die Versuche heute waren ziemlich unterhaltsam.	☐	☐	☐	☐
i) Ich habe mir heute viel Mühe gegeben.	☐	☐	☐	☐
j) Ich war während des Projekttages heute sehr entspannt.	☐	☐	☐	☐
k) Während des Projekttages heute war ich ängstlich.	☐	☐	☐	☐

l) Für mich ist es wichtig bei den Aufgaben heute gut gewesen zu sein.	☐	☐	☐	☐
m) Trotz der Aktivitäten heute war ich nicht aufmerksam.	☐	☐	☐	☐
n) Nachdem ich eine Weile am Projekttag teilnahm, fühlte ich mich durchaus sachkundig.	☐	☐	☐	☐
o) Ich denke ich habe heute gut abgeschnitten im Vergleich zu meinen Klassenkameraden.	☐	☐	☐	☐
p) Ich habe in den Projekttag wenig Energie investiert.	☐	☐	☐	☐
q) Ich habe mich zu keinem Zeitpunkt am Projekttag nervös gefühlt.	☐	☐	☐	☐
r) Ich bin sehr zufrieden mit meinen Ergebnissen heute.	☐	☐	☐	☐
s) Ich habe mir keine große Mühe gegeben um die Aktivitäten heute gut zu erledigen.	☐	☐	☐	☐
t) Der Tag heute hat mir Spaß gemacht.	☐	☐	☐	☐
u) Ich fühlte mich während des Projekttages unter Druck gesetzt.	☐	☐	☐	☐
v) Diese Art der Aktivitäten kann ich nicht sehr gut.	☐	☐	☐	☐
w) Während ich heute aktiv war, dachte ich darüber wie viel Spaß mir das alles macht.	☐	☐	☐	☐

Publication List

Peer reviewed:

Wiegand, F., Kubisch, A., & Heyne, T. (2013). Out-of-school learning in the botanical garden: Guided or self-determined learning at workstations? *Studies in Educational Evaluation, 39,* 161-168.

Kubisch, F., & Heyne, T. (in revision). Students' alternative conceptions about the lotus effect: to confront or to ignore? *Journal of Biological Education*.

Kubisch, F., Gerstner, S., & Heyne, T. (submitted). Concept mapping about plants and water: a useful consolidation tool for females and a useful recapitulation tool for males. *International Journal of Science Education.*

Heyne, T., & **Kubisch, F.** (in press). Mit Modellen dem Lotus-Effekt auf der Spur. *Unterricht Biologie*.

Not peer reviewed:

Krüger, C., Lutz, M., Schnellbach J., & **Wiegand, F.** (accepted). Fleischfressende Pflanzen - Einblick in die Welt der Karnivoren mittels Stationenlernen. *Schulmagazin 5-10.*

Authors' Contributions

In the following tables the contributions of all authors are listed, who participated in the creation of the manuscripts this cumulative thesis is built on.

Chapter III: Wiegand, F., Kubisch, A., & Heyne, T. (2013). Out-of-school learning in the botanical garden: Guided or self-determined learning at workstations? *Studies in Educational Evaluation, 39,* 161-168.

Study sector	Wiegand, F.	Kubisch, A.	Heyne, T.
Idea of the research topic	++	-	+++
Study design	+++	+	++
Composition of the instruction	+++	+	++
Composition of the instruction material	+++	+	++
Enforcement with the school classes	+++	-	-
Analysis of the results	+++	-	-
Statistics	++	+++	+
Paper writing	+++	+	+

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Chapter IV: Kubisch, F., & Heyne, T. (in revision). Students' alternative conceptions about the lotus effect: to confront or to ignore? *Journal of Biological Education*.

Study sector	**Kubisch, F.**	**Heyne, T.**
Idea of the research topic	++	+++
Study design	+++	++
Composition of the instruction	+++	+
Composition of the instruction material	+++	+
Enforcement with the school classes	+++	-
Analysis of the results	+++	-
Statistics	+++	+
Paper writing	+++	++

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Thomas Heyne

Chapter V: Kubisch, F., Gerstner, S., & Heyne, T. (submitted). Concept mapping about plants and water: a useful consolidation tool for females and a useful recapitulation tool for males. *International Journal of Science Education*.

Study sector	**Kubisch, F.**	**Gerstner, S.**	**Heyne, T.**
Idea of the research topic	++	+	+++
Study design	+++	+	++
Composition of the instruction	+++	++	+
Composition of the instruction material	+++	++	+
Enforcement with the school classes	+++	-	-
Analysis of the results	+++	-	-
Statistics	+++	+	+
Paper writing	+++	++	+

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2011 - 2013 Lecturer: “Fachdidaktisches Entwickeln und Evaluieren im LehrLernGarten”

2011 Lecturer: “ Umweltbildung im Biologieunterricht”

2010 - 2013 Lecturer: “Arbeitstechniken und Schulversuche im Biologieunterricht der Grund-, Haupt- und Realschule”

Conference contributions:

Wiegand, F. *Stationenlernen zu Wasser und Pflanzen.* Oral presentation at the 20^{th} Annual Meeting of the “Verband Botanischer Gärten”, University of Mainz, 2012.

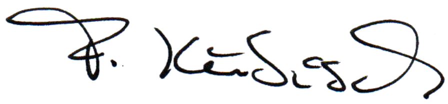
Wiegand, F. & Heyne, T. *Schülervorstellungen zum Lotus-Effekt: Konfrontieren oder Ignorieren?* Poster presentation at the Symposium of the M!ND Center, University of Würzburg, 2012.

Wiegand, F. & Heyne, T. *Schülervorstellungen zum Lotus-Effekt: Integration von Forschung in die Lehre*. Oral presentation at the Annual Meeting of the bavarian “Biologie-Didaktiker”, University of Munich, 2011.

Wiegand, F. & Heyne, T. *Der Lotus-Effekt: Grundlage fachdidaktischer Forschung im LehrLernGarten der Universität Würzburg*. Poster presentation at the 18^{th} International Meeting of the “Fachsektion Didaktik der Biologie (FDdB) im VBIO”, University of Bayreuth, 2011.

Wiegand, F., Poethke, H-J. & Reifenrath, Kerstin. *Defense or dispersal of seeds: A conflict for herbaceous plants?* Poster presentation at the 39^{th} Annual Meeting of the “Gesellschaft für Ökologie”, University of Bayreuth, 2009.

Würzburg, 17 July, 2014



Franziska Kubisch

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Erklärung

gemäß § 4 Abs. 3 Ziff. 3, 5 und 8

der Promotionsordnung der Julius-Maximilians-Universität Würzburg

Hiermit erkläre ich ehrenwörtlich, dass ich die vorliegende Dissertation selbständig angefertigt und keine weiteren als die angegebenen Quellen und Hilfsmittel verwendet habe. Die Dissertation wurde bisher weder vollständig noch teilweise einer anderen Hochschule mit dem Ziel der Erlangung eines akademischen Grades vorgelegt.

Am 16. November 2009 verlieh mir die Universität Würzburg den akademischen Grad der "Diplom-Biologin Univ.". Weder erwarb ich weitere akademische Grade, noch versuchte ich den Erwerb dieser.

Würzburg, 17. Juli 2014,

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