Identifying Deep Sea Gastropods in an Authentic Student-Scientist-Partnership - Learning To Deal With Identification

Manfred Bardy-Durchhalter
University of Vienna, Austrian Educational Competence Centre Biology, Porzellangasse 4/2, 1090 Vienna – Austria, +43/1- 4277-71015, E-mail: Manfred.Bardy-Durchhalter@univie.ac.at

Martin Scheuch
University of Vienna, Austrian Educational Competence Centre Biology, Porzellangasse 4/2, 1090 Vienna – Austria, +43/1- 4277-71015

Franz Radits
University of Vienna, Austrian Educational Competence Centre Biology, Porzellangasse 4/2, 1090 Vienna – Austria, +43/1- 4277-71015

Abstract

Contrary to the relevance of the species concept in biology, the identification of species is scarcely done in school biology. Research literature dealing with identification of species by students is available, but not to an extent one could expect. In this explorative study a marine biologist worked together with 10th graders in school and identified deep sea snails (most of them were limpets) collected on a scientific field trip. This study focuses on the first 100 minutes when the students started to identify the snails initially with the scientist. The process was documented by the approach of field research as an explorative study with a participating observation. Research focused on the questions of the challenges for students in identifying the snails and how teachers and scientists deal with those challenges.

Key words: identification of species, science education, authentic student-scientist partnership

© International Journal of Biology Education, 2013

Introduction

Generating knowledge by identification and classification of species is an important activity of biologists (Bromme, Stahl, Bartholomé, & Pieschl, 2004; Mayr, 1988). Scientists need classified, identified and described species, as core entities in biology for communication (cf. Chambers, 2012, p. 756) and for further analysis in evolution biology and ecology (Mayr, 1988). Biology teachers also use observations or experiments based on the entity of species at school (Gropengießer & Kattmann, 2008). But how do students reach competence in working with this biological entity to get more insights into biological science? Contrary to the relevance of the species concept in biology, the identification of species is scarcely done in class (Randler & Bogner, 2006). Research literature about the identification of species by students is available, but not to an extent one could expect. The process of identification is always closely linked with the specific group of organisms (eg. Bebbington, 2005 [plants]; Hawkey, 2001 [woodlice]; Pfeiffer, Scheiter, & Gemballa, 2012 [fish]; Randler & Bogner, 2002 [birds]) and therefore only limited conclusions about other groups of organisms can be drawn.

In this explorative study a marine biologist worked together with 10th graders in school and identified deep sea snails (male limpets) collected on a scientific field trip. What is special in this project is the fact that the students had never seen organisms like limpets before and that no dichotomous key for the investigated taxa is available, instead photographs and a monograph were used for identification. This paper focuses on the discourses between the students, the biology teacher and the scientists while starting to identify the snails. The objective of the research was to find out which difficulties emerge during the identification of this special group of organisms and how newcomers (our students) and experts (our teacher & marine biologists) dealt with these problems. We give an insight into the identification process of the students under the joint guidance of the teacher and the scientists.

Context of this study

Scientists of the University of Vienna cooperate with students of different Viennese schools in the authentic research fields of biology (e.g. marine biology, palynology and neurobiology). The authentic learning environments for inquiry learning are established by the funded project (www.sparklingscience.at/) and get moderated by teachers and science education researchers. During the student-scientist partnership the students had enough time to participate in essential steps of an open inquiry research cycle, one reference being the framework for competences in science (Mayer, 2007, p. 178). The students' content understanding as well as their learning about epistemology of biological research (Nature of Science) was examined by the project team, as it had been done in previous investigations (Bardy-Durchhalter & Radits, 2011; Heidinger & Radits, 2012).

This study is based on the cooperation with the marine biologist. Within a school subject named "scientific work" she and her assistant scientist worked together with eight students aged 16 to 17 for five months, two hours a week, on research questions of marine biology. The scientists´ sample material was given; she provided snails from habitats occurring in the vicinity of black smokers, originating from one of her own field trips to the Middle Pacific Rise near Mexico. Why did the scientist select deep sea snails? She was interested to give the students insight into her scientific research field – population biology of deep sea habitats. So she looked for samples of organisms providing the students with authentic scientific material according to the following criteria: investigations can be done with equipment of schools; most species were already described in literature; maybe they are of some interest for students; sample was already available in Vienna. The snails were mostly smaller than one centimetre and were preserved in alcohol.

The first meeting between the scientist, her assistant and the students was used for a short introduction into the research field of the marine biologist, followed by a discussion about possible research questions that could be answered by investigating the snails. This discussion was continued in the second unit, resulting in a common agreement about their future research: population biology. In detail, they wanted to investigate the inter- and intraspecific diversity of the sample of snails. The students' results were finally correlated to a sub-theme in a previously published paper (Monka, Ierodiaconoua, Bellgrovea, & Laurenson, 2008) for a more coherent interpretation of their results. One central part of the students' investigation was the identification of snails as a prerequisite for further analysis like species richness or distribution of sexes and size within the populations, or the occurrence of injuries as indicators for predation.

Usually, a dichotomous identification key is used for identification of organisms. In the research field of deep sea hydrothermal vent fauna, however, no dichotomous identification key exists, so differentiation can only be achieved by features derived from descriptive monographs. The scientist used an online version of the handbook of Deep-Sea Hydrothermal Vent Fauna (Desbruyères, Segonzac, & Bright, 2006) as a starting point. She extracted photographs and information about those snails which she expected to find in the given sample. The information about the distribution of species near the sampled location helped her to decide about the inclusion or exclusion of species. She enriched a copy of the monograph with a couple of her own research photographs, and gave it to the students as a manuscript to identify the snails. In this compendium every listed organism had a short description consisting of size, morphology, contemporary known distribution, general remarks, at least one photograph or drawing and relevant papers referring to the sources of more information about this organism. In total, 27 species were included in the manuscript.

For the identification, the students were engaged for eight lessons (50 min each, two lessons per week) to identify the individuals of a randomized sub-sample, drawn by the scientist. The eight students worked in three groups of two or three each. Each group took charge of a part of this sub-sample and started to work. Within a group each student investigated the snails – referring to their small size – with a microscope, discussing cases of uncertainty with their colleagues, the teacher and both scientists. In the first lesson, the scientists had introduced the students and the teacher into the identification of the snails. For the following three weeks the identification was continued without the scientists' help because they had to leave for a field trip. Each group established a list of successfully identified snails and finally all results (species names, abundance, sex, size, age, injuries etc.)

were merged together in one table for further population analysis. In all, the students could differentiate between eight species in this sub-sample: Cyathermia naticoides, Eulepetopsis vitrea, Lepetodrilus elevatus (with nearly 80% abundance the most common one), L. ovalis, L. pustulosus and Rhynchopelta concentrica and two unknown species titled “XY” and “XX”. The unknown species XY and XX were only found once and could not be satisfactorily assigned to any species documented in the handbook of Deep-Sea Hydrothermal Vent Fauna. The scientist sent them to another specialist for further investigation, but they never got identified. Cyathermia naticoides was the only identified snail with a shape like well-known terrestrial snails, Eulepetopsis vitrea had a transparent shell and could therefore be identified quickly.

For the differentiation of the other species, three of the genus Lepetodrilus and Rhynchopelta concentrica, the following distinctive features had to be used (detailed illustrations of these four species can be found in the appendix): the position of the apex (the growth centre of the snails), the height of the shell viewed in cross-section, and the presence or absence of striae on the shells´ surface. The striae are radial, fin shaped grooves starting at the apex and running to the edge of the shell, right-angled to the concentric growth grooves. In contrast to L. ovalis – having a more centred apex – L. elevatus, L. pustulosus and R. concentrica have an apex oriented to the front of the shell. R. concentrica has a higher shell cross-section than L. elevatus and L. pustulosus. Those two species could be differentiated on account of the presence (L. pustulosus) or absence (L. elevatus) of striae.

All species, but not all individuals of a species, had highly variable surface structures like shell colour, black or brown points or hollows as well as white calcareous depositions complicating the identification process.

Theory of species identification

In the classroom, “scientific knowledge is presented as absolute truth and as a final form” (Duschl, 1988, p. 51), in school textbooks scientific methods are used mainly as instruments for demonstration or confirmation of effects (Chinn & Malhotra, 2002, p. 179). This runs contrary to efforts in contemporary science education to develop a well-informed understanding of science (eg. Duschl & Grandy, 2008; Lederman, 2007). In school, the knowledge about and the understanding of scientific concepts seldom enjoy a status equal to the subject matter (Lederman, 2007, p. 872).

Two of the main scientific concepts in life science are the identification and classification of organisms. Species are considered to be the core entities of biological theories (Cracraft, 1989) and core objects of research in many disciplines of biology. The philosophy of Biology (Mayr, 1988) as well as Science Education (Gropengießer & Kattmann, 2008; Mayer, 2007) specify comparison and identification of species as essential empirical methods of biological scientific inquiry. In school context, the students’ need for knowledge about species is emphasized as a major prerequisite for the understanding of ecology or biodiversity (Lindemann-Matthies, 2002; Randler, 2008, 2009; Randler & Bogner, 2006). Studies in science education give an overview of students ordering, classifying or identifying species, but seldom focusing on the identification process itself and possible difficulties in the interaction of students with their objects of interest, the organism.

At the level of higher taxa, studies unfold the students´ implicit ordering criteria for animals and plants. Kattmann and Schmitt (1996) and Kattmann (2001) point out that animals are mainly ordered by habitat or locomotion, whereas plants are classified by appearance, usefulness (eatable!) and habitat as well (Krüger & Burmeister, 2005). Detailed studies investigate identification skills on different taxa of plants (eg. Bebbington, 2005) or animals (eg. Randler & Bogner, 2002) and survey the status quo or test the effectiveness in pre/post designs, seldom focusing on problems within identification itself (eg. Affeldt & Groß, 2011; Bromme, et al., 2004; Stahl & Groß, 2011).

In biology, for the identification of organisms, mainly two tools are used: identification books or dichotomous identification keys. The former are often used in popular biology books, the latter are usually used at university and focus on specific taxonomic groups. A study compared the students' success in identifying reptile species by using identification books or dichotomous keys, but these data did not reveal any differences in the students' effectiveness (Randler & Bogner, 2006). Identification books are usually illustrated and provided with additional information as well as diagnostic characters about the organisms. They are designed for amateurs as well as for professionals. In some taxa, like birds or mushrooms, they represent the most popular identification material (Scharf, 2009). Randler and Bogner (2006) highlight a main disadvantage of identification books: Students often focus on the illustrations alone and ignore additional descriptions of diagnostic characters.

In scientific biology accurate identification is needed, therefore dichotomous keys, structured by diagnostic characters, are often preferred for species identification. They are considered to be "scientifically more precise and foster the understanding of scientific terms" (Randler, 2008, p. 227). Identification keys guide biologists through taxonomy by structured dichotomous decision trees (cf. Bromme, et al., 2004, p. 54 ff.). In each junction of the decision tree a decision should be made between two different features. An ideal diagnostic character consists of one attribute, owned only by organisms of one branch of the decision tree. Biologists have to compare the morphology of the organism with the diagnostic character in the decision tree. Sometimes neither one nor the other diagnostic character really fits and the biologists have to decide whether one or the other features applies better to the organism in question. This is due to the fact that even within one species there is a continuum of variance of morphological features in e.g. size and form. Each decision, based on the evaluation of the feature in question, leads a step closer to the identification of the investigated organism, to its species name.

For students, junctions in a decision tree of an identification key can be interpreted as a "problem solving process" (Bromme, et al., 2004, p. 56). Scientific problem solving is seen as purposeful thinking and acting in situations where no established routines are available (Mayer, 2007, p. 178). In the process of identification these problems are ill- defined problems. In dealing with ill-defined problems one cannot exactly specify neither which boundaries define the problem nor when the problem is actually solved (Betsch, Funke, & Plessner, 2011, p. 153). Generally the problem with identification is rooted on one hand in the enormous diversity of species itself and on the other hand with the broad intra-specific variability, manifested in the variance of morphological or genetic structures within a species. In natural science and philosophy of biology these two problems are still unsolved (and probable insolvable). The so called 'species problem' has the dispute in focus about the question 'what is (the nature of) a species?' (e.g. Dobzhansky, 1935; Ereshefsky, 2010; Ghiselin, 1974; Hull, 1997; Mayr, 1996; Reydon, 2013; Rieppel, 2007; Ruse, 1995).

Bromme, et al. (2004) outline the ability of differentiating variable species within the psychological construction of mental representations. A mental representation of a species does not consist only of one essential prototype, it includes all kinds of possible variations of significant features needed to identify them (Bromme, et al., 2004, p. 55). These authors subsume one main obstacle for the development of an expertise of identification skills: "for novices it is nearly impossible to learn plant identification without a supervisor, because of the necessity of case-based learning" (Bromme, et al., 2004, p. 56). Guidance and providing a scaffold for the students are often mentioned as important factors for successful inquiry learning environments (cf. Furtak, 2008). This study follows the claim of Bromme, et al. (2004) and established a learning environment for a guided identification of species – the students' investigations of snails were given a scaffold by the marine biologist. The research focus was on strategies for identification exemplified by the discourses between the students, the teacher and the scientist during the identification process.

Research question

What are the challenges for students in identifying snails and how do teachers and scientists deal with those challenges?

Methods

In close cooperation, the students were engaged in identifying the snails for four units, each of 100 minutes. This study focuses on the first unit when the students started to identify the snails for the first time. The process was documented by the approach of field research as an explorative study (Bortz & Döring, 2006; Girtler, 2001) with a participating observation (Bortz & Döring, 2006; Mason, 2002), collecting additional data in field notes (Emerson, Fretz, & Shaw, 1995).

The discussions and processes of identification were audio recorded. The principal investigator (first author of this paper) carried along the audio recorder. The objective of the participating observation was to document the discourses within the groups and with the teacher and the scientist. Verbatim transcripts use pseudonyms for the students and functions for ´teacher´, ´scientist´ and ´assistant´ for the scientist´s assistant. The transcript was analysed using summative qualitative content analysis, with guiding questions (following the research questions) according to Mayring (2007). Additional material like the manuscript with diagnostic photographs and additional information of the snails was added and used for a deeper understanding and rewriting of the dialogues observed, mainly to track the discourses about diagnostic characters of species. Whenever the discourses included discussions about whether the four similar limpet species in question have e.g. ´striae´, the identification manual was used beside the transcript to illustrate the discourse. In the material presented we also refer to the material in the appendix where one can look up the specific features of the limpets being discussed.

Results

The students met the scientist in the biology laboratory at school where they started the identification of the snails. The scientist brought along her assistant to support her in answering the students' questions. She introduced the objectives of this unit and exemplified the purpose: to learn how to identify snails as a basis for further investigations in biodiversity and population dynamics. The teacher assisted her with a short technical introduction into working with binocular microscopes, and then the students got the snails for identification. The samples were placed in petri dishes under the binocular microscope, and provided with water to prevent the dehydration of the snails' abdomen.

The scientist's role of teaching

To support the student the scientist introduced the working material: „It is not an identification key, because - as you can easily see - most species can be recognised immediately by looking at them (00:15:29) […] with keys you have to look exactly at morphological or anatomical features, but those genera or species are quite different, so you can optically identify them (00:16:30)". Her assumption was that the students could easily compare the photographs in the manuscript with the different specimen and therefore quickly identify the species in the probe. When the students started to work, the scientist walked around and supported the identification process. For that purpose she joined the students´ work and discussed individual snails under the binocular microscope, tried to unfold her perspective on the specification of the organism, and added her tacit knowledge about how to distinguish the snails, beyond the characterization in the manuscript. From the beginning she noticed that the students did have problems in identifying similarity between the snails. "No, that one is much too … If you look at the side of the limpet it is totally different from this one here in the manuscript. (00:24:03)" She quickly adopted her strategy and started to teach identification, to show the students the different features she would apply for differentiation. "It is not Lepetodrilus pustulosus. Do you know why? L. pustulosus has very fine grooves. Many fine grooves. Look through the binocular microscope. […] The limpet here is really smooth, isn't it? That is the most common one – L. elevatus (00:25:48)." The scientist switched from group to group in each case teaching and discussing predominantly the diagnostic characters between the species of the genera Lepetodrilus and Rhynchopelta, focusing on the position of the apex, the presence of radial striae, or the height of the shell in cross-section. In her characterisation of the organisms, the snails did not have black points or white calcareous surface structures, she tried to guide the students´ identification process by reducing complexity of all visible morphological structures of the limpets to an ideal organism consisting virtually only of the diagnostic characters. When the scientist talked explicitly of black or white shell structures she implicitly declared them to be aberrations distracting from differentiation: “However, as you can imagine, those fine grooves are hard to see, because the shell is so much covered (00:38:20)” or “This snail incidentally has these tussocks here, these depositions. But there exist millions of deposition structures. (01:19:53)” later on.

She realized that the photographs in the manuscript did not facilitate the students' ability to apply similarities or diagnostic characters to the living organisms under the binocular microscope, as she had expected. So the scientist assumed that the rare species L. ovalis was often overlooked by students and was assigned to the most similar species L. elevatus. She changed her teaching strategy to make the distinguishing features more explicit. She picked individual limpets from L. ovalis and L. elevatus which supported her intention to characterize that particular diagnostic character best and placed those organisms under one petri dish of a binocular microscope for a comparison of the morphological structures. Then she highlighted the diagnostic characters with respect to the two “ideal” limpets chosen and called the students to her microscope to have a look: “Here is a Lepetodrilus ovalis now, come and have a look! For this species, the apex, the lappet, is as not far from the front edge as it is in Lepetodrilus elevatus next to it, but more in the centre (00:56:45)”. At the microscope, all participants lively discussed the application of different possible features. Nearly the same thing happened half an hour later with two other species in focus. Another pair of taxa difficult to distinguish are the species Rhynchopelta concentrica and Lepetodrilus elevatus. Again the scientist assumed that those two species were often subsumed within L. elevatus. Like in the example above, she presented individuals from both species under one binocular microscope and exemplified the diagnostic characters between Lepetodrilus elevatus and Rhynchopelta concentrica: “The shell of L. elevatus is lower, the one of R. concentrica is higher (01:27:52)”, the teacher assisted her adding an additional perspective: “Yes. L. elevatus is lower, and the cross-section of the shell of R. concentrica goes up steeply (01:27:54)”. When Alexander asked an essential question, “What is a Rhynchopelta? (01:27:55)” the teacher replied, “It is the last photograph in the manuscript (01:27:59)” and a colleague, Thomas, tried to help Alexander as well: “The one closer to you under the binocular microscope is the higher one (01:28:06)”. After a while of discussion Lukas remarked, “But they look almost identical. They only differ in their height. It is really hard to find out, if you do not have them lying side by side (01:29:34)”.

Students’ challenges in identifying snails

The students stated that it was not easy for them to differentiate the limpets. As the majority of snails in the sample belonged to one species only (nearly 80% Lepetodrilus elevates) it was hard to distinguish the intraspecific variability of this species from features exclusively belonging to other limpet species. Many of the proposed diagnostic characters were considered as not exclusively related to just one particular species. At first the students’ strategy for identifying limpets was to find similarities between the limpets in the sample and limpets shown in the manuscript. Thomas showed the scientist a limpet in his binocular microscope and argued, “It looks similar to that photograph in the manuscript (00:27:40)”. Another strategy was used by Stefan. He also used similarities, but, additionally, tried to establish colour as the most obvious diagnostic character to distinguish the species of the common genus Lepetodrilus spp. as presented in the manuscript: “Most likely, this is L. pustulosus here, but its colour is wrong (00:31:11)”. In both cases the scientist’s reaction focused on other diagnostic characters (see her answer to Stefan): “No, you should not look at the colour. Take a look again to see if the snail in your microscope has such very fine transverse grooves. Not growth grooves, such as the ones when the snail gets larger, but very fine transverse grooves (00:31:29)”. Repeatedly she refused the features found by the students, in that case colour, and tried to implement, in her view, more effective ones. To find diagnostic characters, Stefan and Thomas, like all other students, focussed only on the photographs and ignored additional descriptions in the manuscript.

Talking about – what and how?

In their discussions the students used their everyday language and many spontaneous colloquial terms, but one could observe an increase of scientific terms as well. The scientist – trying to avoid too much of scientific language – used her own colloquial terms too, but used scientific terms from time to time as well. That mixture characterised most of the discourses. The variability of terms within the process of negotiation about the identification features is significant for the identification process itself.

The struggle to find helpful diagnostic characters was always closely linked with the need for common understanding with respect to the descriptive terms applied to the features. To communicate about the visible and distinguishable structures and shapes without detailed technical terms given, all participants – students, teacher, scientist and assistant – used terms of everyday language for the unknown structures.

Applying non-scientific terms to biological structures had led to several misunderstandings, which structure was actually meant by a specific word. This can be exemplified by the concept of injury in the colloquial language. Injuries were integrated into the follow-up investigations as indicators for predation and offered access to morphological structures of everyday life. Sarah found shell structures which she associated with this term and asked the teacher for validation: “*I think I have an injury (00:31:45)*”. The following discourse shows that the every-day term “injury” meant three different things for the three persons involved, but at the beginning each of them believed that they spoke about the same surface structures. The teacher looked through the binocular microscope and confirmed her assumption: “*The cut here at the front? Yes, I would agree, that’s an injury (00:32:29)*”. Claudia, working in a group with Sarah and searching for something she associated with injury, agreed to her colleague: “*Yes, I think I have the same thing as you. (00:33:27)”,* she continued and asked, *“There are such black points. So, those black points are injuries?* (00:33:29)”. The teacher hesitated and tried to reinsure, asking: “*Sarah, did you mean the thing at the front of the rim of the shell? Otherwise, I saw something completely different. (00:33:42)*”.

Table 1. *List of terms taken from everyday speech with the respective morphological feature*

original German terms	***translated terms from discourses***	***biological terms***
Dinger (01:09:11)[3], (01:27:29) [2], kleine Noppeln (01:09:06)[1], Nopperln (01:20:17)[1], Noppen (01:27:29)[2], Hubberl (regularly)[1,2,3,4], Rillen (regulary)[1,2,3,4], feine Rillen (00:25:44)[3], (00:35:11)[3], (00:36:07)[3], Querrillen (00:31:29)[3], Zungenschnalzen [onomatopoetic] (01:09:06)[3], Protuberanzen (01:09:08)[3]	things (01:09:11)[3], (01:27:29)[2], pimples (01:09:06)[1], (01:20:17)[1], (01:27:29)[2], hubberl (regularly)[1,2,3,4], grooves (regularly)[1,2,3,4], fine grooves (00:25:44)[3], (00:35:11)[3], (00:36:07)[3],longitudional grooves (00:31:29)[3],tongue clicks [onomatopoeic] (01:09:06)[3], protuberances (01:09:08)[3]	radial protuberances, radial striae[5]
Kreisförmige Rillen (01:02:50)[2], Rillen (regularly)[1,2,3,4], Wachstumsrillen (00:31:29)[3], Wachstumsringe (regularly)[2,3], Wachstumsrinnen (00:41:42)[2]	concentric grooves (01:02:50)[2], grooves (regularly)[1,2,3,4], grow grooves (00:31:29)[3], grow rings (regularly)[2,3], grow channels (00:41:42)[2],	growth rings of the shell, striae[5], concentric ridges[5]
Kalk (regularly)[1], weißes Zeug (01:02:14)[1], Büschel (01:19:43)[3], Pusteln (00:29:03)[3], (00:41:01)[2], Kalkmist (00:41:04)[1], bedeckt (00:38:20)[3], verkalkt (01:08:37), Ablagerungen(regularly)[1,2,3,4], weißer Belag (01:33:33)[1]	lime (regularly)[1], white things(01:02:14)[1], tussocks (01:19:43)[3], pustule (00:29:03)[3], (00:41:01)[2], (00:41:01)[2], calcareous rubbish (00:41:04)[1], covered (00:38:20)[3], limed up (01:08:37)[3], deposition (regularly)[1,2,3,4], white covering (01:33:33)[1]	calcareous depositions on the shell
Bläschen (00:38:26)[1], (00:39:14)[1], (00:39:50)[2]	small bubbles (00:38:26)[1], (00:39:14)[1], (00:39:50)[2]	not clarified, most likely either “black points“ or “calcareous depositions”
Brandflecken (00:39:41)[1], (00:42:09)[1], (00:43:51)[1], (00:43:57)[1], eingebrannte Löcher (00:34:29)[3], braune Punkte (01:03:41)[2], (01:03:42)[1], schwarze Punkte (regularly)[1,2,3,4], Verletzungen (regularly)[1,2,3,4]	marks burned by fire, (00:39:41)[1], (00:42:09)[1], (00:43:51)[1], (00:43:57)[1], holes burned by fire (00:34:29)[3], brown points (01:03:41)[2], (01:03:42)[1], black points (regularly)[1,2,3,4], injuries (regularly)[1,2,3,4]	not clarified; most likely fungi or bacteria entering the periostracum causing a hollow and/or discolouration
Delle (00:33:50)[1], Cut (00:32:04)[2], Verletzungen (regularly)[1,2,3,4]	hollow (00:33:50)[1], cut (00:32:04)[2], injuries (regularly)[1,2,3,4]	healed shell injuries[3]
Schale (regularly)[1,2,3,4]	shell (regularly)[1,2,3,4]	shell
Rand (regularly)[2,4]	rim (regularly)[2,4]	margin[5] of the shell
Schwammiges (00:26:32), Schnecke (regularly)[1,2,3,4], Muschel (00:41:28)[1], (00:41:42)[1]	fungous thing (00:26:32), snail (regularly)[1,2,3,4],, mussel (00:41:28)[1], (00:41:42)[1]	snail body (mainly the foot) or snail (body and shell)
Spitz/Spitzel (regularly)[2,3,4], Zapfen (00:41:55)[2], (01:30:57)[2], (01:30:58)[4], vorne eingeknickt (00:41:23)[1], Überdings (00:41:45)[1], Wölbung (00:41:48)[1], Apex (regularly)[2,3], Knopf (01:04:41)[2]	top (regularly)[2,3], cone (00:41:55)[2], (01:30:57)[2], (01:30:58)[4], in the front buckled (00:41:23)[1], overshooting thing (00:41:45)[1], bulge (00:41:48)[1], apex (regularly)[2,3], knob (01:04:41)[2]	apex

Source: [1)] student [2)] teacher [3)] scientist [4)] assistant [5)] manuscript
“regularly” was used if the term was mentioned more than five times by persons

Sarah finished the discussion by clarifying her original perspective: "*No, not the black points, I meant a ′hollow′ in the middle of the shell. (00:33:50)*". Interestingly, they did not try to find out what kind of injuries they had seen; the discourse continued but focused only on the clarification of the most eye-catching features, the black points. For that reason they asked the scientist for her expertise, but she could not solve the origin of the black points either: "*I do not know what those black points are. They look as if caused by something hot. If this is an injury, I cannot say, but they look like holes burned by fire (00:34:33)*". The origin of the dark-coloured (brown to black) shell structures on many individuals of the investigated specimen could not be clarified until the end of this project.

Within the unit analysed, some progress concerning the students' strategies could be recognized. Whereas, at the beginning, differences were only argued with respect to the most obvious diagnostic characters (like colour), students soon began to underpin their argumentation of identification results with diagnostic features initiated by the scientist. Sarah reported to the scientist that she had found a *Rhynchopelta concentrica*: "*Though it is very similar to Lepetodrilus elevatus - but the Rhynchopelta is much higher. (00:44:41)*". In the discussion about the differences between *Lepetodrilus elevatus* (lower shell) and *Rhynchopelta concentrica* (higher shell), Sarah offered her expertise once more. When the scientist stated her opinion about the confusion of those species "*Within the species which we identified as L. elevatus, there are certainly R. concentrica included […]. Because elevatus is low … (01:25:31)" Sarah agreed "That's what I said! And Rhynchopelta is high! (01:25:44)*".

The teacher's intermediate role when identifying snails

In the discourses, both the teacher and the scientist's assistant held an intermediate position between the students and the scientist. He struggled, together with the students, to find valid features for identification. When the teacher tried to examine a sample on his own, he started a discussion with a student about possible diagnostic characters between Lepetodrilus pustulosus and L. elevatus and asked for the student's expertise. "Look at this, Daniel. Is that a L. pustulosus too? (01:03:17)" Daniel denied, arguing, "No, I don't think so, because your limpet has those black points. These do not appear on L. pustulosus. You can check this in the manuscript (01:03:44)". The teacher asked for confirmation: "Those brown points? They only appear on elevatus? Do they really count for differentiation? (01:03:49)" and after Daniel's repeated confirmation he subsumed, "Well, then it is fine! That means this has to be an L. elevatus. (01:03:51)".

Being a novice in identifying such special organisms as limpets, he had as little knowledge as the students at the beginning. His learning strategy was different from the students' one. Whereas the latter were often satisfied with the diagnostic characters they were told by the experts (the scientist as well as the teacher) to validate their identification, the teacher insisted on the explication of diagnostic characters until he gained enough understanding of those criteria which helped him to solve the problem of identification.

This can be exemplified by the following discourse where concentric growth grooves were initially interpreted as protuberances characteristic of only one species in the sample – Lepetodrilus pustulosus. A limpet in the binocular microscope had grooves, therefore the teacher named it L. pustulosus, and asked the assistant for validation. She confirmed and the teacher underpinned his identification: “Because it has the grooves (01:07:44)”. Again the assistant agreed: “Yes, because of the grooves. The other species are smooth (01:07:46)”. The scientist asked for clarification, “Are the grooves growth rings or radial Hubberl? (01:07:57)” “I did not see the radial Hubberl (01:07:58),” the teacher answered and continued, “Maybe I looked at the wrong shell structures. Show me the Hubberl again on the photographs, please. What do you mean? (01:08:03)”. The assistant remarked, “She means that, Lepetodrilus pustulosus has to have radial Hubberl. (01:08:10)” and the teacher concluded, “Okay, then this species here is a different one than L. pustulosus! (01:08:19)”.

The teacher’s role as a moderator of students’ learning

The teachers’ insistence on the explication of diagnostic characters unfolds his professional pedagogical knowledge. His aim is to get good arguments for the distinguishing by his students. So he encouraged his students to discuss the specified criteria for identification. Claudia found a snail with a particular shell form in the manuscript which corresponded to the organism under her binocular microscope and asked her teacher for advice. “Please have a look. This Rhynchopelta here is really buckled! (00:41:23)” The teacher agreed, “Yes, it rather looks like this Rhynchopelta. Especially, when you look at the rim: It is abruptly cut off here but the rim of the other snail gets gradually thinner (00:41:35)”. Within the dialogue is not identifiable which species was the opposite one [most likely L. pustulosus, maybe L. elevatus], but Stefan contradicted, “But this one’s [pustulosus? elevatus?] rim is getting gradually thinner too! […] And there is such an over-sized bulge [the apex] at Rhynchopelta in the manuscript which that limpet in the binocular microscope should have too (00:41:45)”. Sarah argued briefly, “Well, it has! (00:41:46).” But the teacher intervened, asking again, “What over-sized bulge do you mean? (00:41:47)” Stefan explained, “This forward bulge, and the fact that it retreats again (00:41:48)”. The teacher asked again, “That the shell is bulged? Yes, but that's just the way it is! The limpet under the binocular microscope is really bulged. Oh, you mean that the cone [the apex] in the manuscript juts out over the rim. Well, have a look again: The cone really protrudes the rim! I think – like Sarah does – that this is Rhynchopelta. (00:41:55)”. Sarah, now satisfied, said, “Perfect! (00:41:59)”, Stefan was convinced and cheered “We have got a new one! You can write Rhynchopelta concentrica! (00:42:04)”

Only seldom did such discussions about diagnostic characters arise unstimulatedly within a group of students. Mostly, they were initiated by the teacher like in the examples above or when the teacher was asked for validation or advice. For another example, Sarah assumed, “It could be that one in the manuscript, but I do not know. It has a different colour. (00:40:47)”. The teacher agreed, “Yes, they really look very similar. […] But under the binocular microscope it has such pustules which are not shown here in the manuscript. (00:40:52)”. Stefan contradicted his teacher’s arguments that “the pustules are only calcareous deposits! (00:41:04)”. The teacher supposed, “But maybe it is just this species that has such deposits. In that case it would be unique. (00:41:10)". In such situations of uncertainty he often addressed the scientist for her expertise, "Do you know if those calcareous deposits are significant only for Lepetodrilus elevatus? (00:41:12)". When she denied, the teacher added, "Well, that would have been too easy! (00:41:22)".

The discussions about diagnostic characters between the students and the scientist were different from the teacher - student debates. Whereas the teacher often negotiated about the diagnostic characters, the scientist was not expected to discuss her validity, her role was to give her expertise and to teach about species identification.

Discussion

Ordering as epistemological skill

Reported ordering schemata like habitat or locomotion (cf. Kattmann & Schmitt, 1996) could not be applied. Instead, a high relevance of the criterion "appearance" of an organism was found – also induced by the manuscript with the photographs. As Krüger and Burmeister (2005, p. 99) assumed, the ordering criterion "appearance" can be used to trigger the students´ attention to the principles of taxonomic ordering criteria, a slow shift could be observed in this study. At the beginning the students ordered the specimens using implicit criteria of appearance and similarity, later on they used diagnostic characters to compare organisms of two species. Due to the effort of the scientist to repeat the best diagnostic criteria as well as the teacher's effort to discuss the different quality of features, the students acquired epistemological skills like comparing and ordering the snails with respect to diagnostic features. Based on evolution, the variability of species makes ordering a unique epistemological activity in biology, compared to other natural sciences (cf. Mayr, 1988). The reflection and explication of the technical skills (of comparing and ordering) helped the students to gain additional insight into taxonomic knowledge itself.

Different challenges for students, scientist and teacher

Although the sample explored represented snails from very distinct taxa (up to super families), students had to deal with striking similarity in the case of four limpet species (cf. Appendix). The students' focus on the similarities of photographs in the manuscript resulted in their struggle to find valuable features to distinguish the various snails. This finding also corresponds to the discussion of Randler and Bogner (Randler & Bogner, 2006) that students obviously tend to focus on illustrations alone and ignore additional descriptions of diagnostic characters. But whenever our students had understood a diagnostic feature which, in their view, was well defined – like injuries which they knew from their own colloquial language – then this feature was immediately identified by other students as well. Situations like those were delightful and stimulating for the students' curiosity, more than looking for the position of the apex, if it was more lateral or central on the shell.

The scientist's first approach (to teach the diagnostic characters of all species) did not reduce the students' difficulties; so she changed her strategy and displayed adhoc examples of different dichotomous diagnostic characters under the binocular microscope. Those individuals, estimated to be prototype specimens of a species, helped to illustrate relevant identification features. They were also used as reference objects in the identification process and could be seen as a crucial factor which enabled the students, in intensive discussions in front of the binoculars, to construct their own mental representation and to move a step forward towards a virtual identification key.

The scientist, like in her own research projects, accentuated her knowledge as well as her non-knowledge – like the origin of the black points. This provided opportunities for the teacher's own curiosity. Like in real science, non-knowledge is the more interesting part of a research project. He was a novice as the students were, but he is also a trained biologist. Experienced in working with identification keys, he quickly learned how to adapt his previous knowledge to the identification process of limpets. This enabled him to engage in his professional role as a moderator, allowed him to open space for his students for self-engagement, and bridged the gap between the scientist's expertise and the students' non-expertise or lack of knowledge. From a theoretical perspective on learning, the identification process became more constructivist with the teacher insisting on arguments and discussions with both the scientist and the students about their respective conceptions of diagnostic characters.

Constructing mental representations

The discussions analysed document the experience of the scientist how to deal with variability and extract applicable features within the similarity of organisms. She acquired, in the sense of Bromme, et al. (2004), her mental representation. The scientist used photographs of the manuscript as mnemonic for different features and immediately inferred information from the pictures to the limpets under her binocular microscope. Whenever the scientist presented diagnostic characters characterising an essential prototype of limpets she knew that ideal prototype specimens do not exist, but she "constructed" them to provide the students with applicable diagnostic characters.

The students, on the other hand, began to adhere to the variability of surface structures (colour, calcareous deposits,…) to apply features for differentiation. Initially they lacked exploring the variability of all individual snails to construct their own mental representations (Bromme, et al., 2004). Students had to develop such perspectives too, to be able to continue on their own with the identification of snails. In every-day life students easily classify tables - red ones, big ones, wooden ones made for work or dining - into the mental representation of the kind named "table" In the discourses analysed they just started to assemble knowledge for building mental representations of deep sea vent limpets. Of course the variation within species represents more complexity than red or big tables, but the example of ordering human furniture illustrates the basis of the students' first ordering criteria for limpets, like colour or size, just like in every-day life classification. On the students´ part, this initial "blindness" – take blindness as a metaphor for a lack of applicable conceptions – was sometimes a source of frustration. When students asked the scientist to validate the result of their identification of a limpet under the binocular microscope, she sometimes argued by using diagnostic characters for another identification result. Very often, the students – like Stefan, as mentioned above – could not see and understand why those features which the scientist mentioned should characterize a species better than theirs. Whereas students often gave up in such situations, the teacher insisted on arguing and discussing the different features. This function of the teacher can be seen as a crucial one for learning to understand the scientist's perspective.

We suppose that presenting two "ideal" limpets in one petri dish under one binocular microscope had helped the students to reduce the structures of the organisms to some (common) representative identification features. This could be facilitated by directly comparing two three-dimensional objects under the binocular microscope, which obviously needs less capacity of abstract thinking than the comparison of a limpet under the binocular microscope with a picture or even a scientific drawing in a book. The order of magnitude, three dimensional structures, or the colour of objects can easily be compared at that very moment, as Lukas did. We also assume that the students´ discussions about diagnostic characters were impulse for constructing their own mental representations of the morphological structures of limpets.

Evolution as tacit knowledge of biology

The students lack the implicit "feeling", some kind of tacit knowledge, for applicable diagnostic characters, which the scientist has already developed in her career, just as the teacher in his studies. A main part of that tacit or implicit knowledge seems to concern evolutionary development and genealogical trees as an interpretative background. It can be assumed, for example, that the marine biologist knows that shell colour has a broad variability even within the individuals of a population of the same species. This ambiguity immediately excludes the attribute of "shell colour" as a candidate for valid features of identification. On the other hand, the same implicit evolutionary and genealogical perspective helps her to identify good applicable features – like the ontogenetically caused position of the apex on the shell or radial grooves on L. pustulosus – very quickly. Those phylogenetically conserved morphological structures – in spite of all possible variations within the species – represent stable anchors for applicable diagnostic characters.

We assume that beyond Bromme's et al. (2004) mental representations the combination of both tacit knowledge of biology (consisting of evolutionary thinking) and experienced knowledge enable the scientist to recognize and quickly apply the diagnostic characters of individual snails.

Conclusion and outlook

To support learning environments for species diversity it seems to be crucial that teaching includes evolutionary perspectives like homologies and analogies to unfold the similarities or dissimilarities of phylogenetic groups (cf. Kattmann & Schmitt, 1996; Krüger & Burmeister, 2005). Furthermore, in biology classroom science, it is important to explicitly point to the inherent natural variability of all biological organisms (caused by evolution), as well as to point out diagnostic characters as tools (to "impose a discrete classification upon an essentially continuous phenomenon" (Chambers, 2012, p. 756). To establish learning environments with species as core entities the teacher needs classified, identified and described species. Only then can they be used for biological communication and further analyses based on these entities, as it was achieved by the students in this paper.

The fact that evolution causes a different ordering and classification of taxa as compared to other scientific fields constitutes a concrete need for more investigation about the Nature of Biology in science education.

Acknowledgement

The financial support by the Austrian Federal Ministry of Science and Research (SPA/03/020/KiP2) is gratefully acknowledged. The authors would also like to thank Kerstin Kremer for reading and commenting on an early draft of this paper. Writing the paper was also supported by "Strohkopf".

References

Affeldt, S., & Groß, J. (2011). Im Winter haben Bäume keine Blätter. Fachdidaktische Herausforderungen bei der Ansprache von Gehölzarten. *Erkenntnisweg Biologiedidaktik, 10*, 23-37.

Bardy-Durchhalter, M., & Radits, F. (2011). Wissenschaftsverständnis von SchülerInnen *Erkenntnisweg Biologiedidaktik 9*.

Bebbington, A. (2005). The ability of A-level students to name plants. *Journal of Biological Education, 39*(2), 63-67.

Betsch, T., Funke, J., & Plessner, H. (2011). *Denken – Urteilen, Entscheiden, Problemlösen*. Berlin, Heidelberg: Springer.

Bortz, J., & Döring, N. (2006). *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler* (4., überarbeitete Auflage ed.). Heidelberg: Springer Medizin Verlag.

Bromme, R., Stahl, E., Bartholomé, T., & Pieschl, S. (2004). The case of plant identification in biology: When is a rose a rose? Development of expertise as acquisition and use of robust and flexible knowledge. In H. Boshuizen, R. Bromme & H. Gruber (Eds.), *Professional Learning: Gaps and Transitions on the Way from Novice to Expert* (Vol. 2, pp. 29-47). Dordrecht: Kluwer Academic Press.

Chambers, G. (2012). Review of The species problem: seeking new solutions for philosophers and biologists. *Biology & Philosophy, 27*(5), 755-765.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Cracraft, J. (1989). Species as Entities of Biological Theory. In M. Ruse (Ed.), *What the Philosophy of Biolgy is* (pp. 31-52). Dordrecht: Kluver Academic Publishers.

Desbruyères, D., Segonzac, M., & Bright, M. (Eds.). (2006). *Handbook of Deep-Sea Hydrothermal Vent Fauna* (2. ed.): Land Oberösterrreich, Biologiezentrum der Oberösterreichische Landesmuseen.

Dobzhansky, T. (1935). A Critique of the Species Concept in Biology. *Philosophy of Science, 2*(3), 344-355.

Duschl, R. A. (1988). Abandoning the scientistic legacy of science education. *Science Education, 72*(1), 51-62.

Duschl, R. A., & Grandy, R. E. (2008). Reconsidering the Character and Role of Inquiry in School Science: Framing the Debates. In R. A. Duschl & R. E. Grandy (Eds.), *Teaching Scientific Inquiry. Recommendation for Research and Implementation* (1. ed., pp. 1-37). Rotterdam: Sense Publishers.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1995). Writing up fieldnotes I: From field to desk. In R. M. Emerson, R. I. Fretz & L. L. Shaw (Eds.), *Writing ethnographic fieldnotes* (pp. 39-65). Chicago: University of Chicago Press.

Ereshefsky, M. (2010). Species. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/archives/spr2010/entries/species/)* (Spring 2010 ed.).

Furtak, E. M. (2008). *The Dilemma of Guidance: An Exploration of Scientific Inquiry Teaching*. Saarbrücken: VDM.

Ghiselin, M. T. (1974). A Radical Solution to the Species Problem. *Systematic Zoology, 23*(4), 536-544.

Girtler, R. (2001). *Methoden der Feldforschung*. Wien: Böhlau.

Gropengießer, H., & Kattmann, U. (Eds.). (2008). *Fachdidaktik Biologie. Die Biologiedidaktik begründet von Dieter Eschenhagen, Ulrich Kattmann und Dieter Rodi* (8. ed.). Köln: Aulis.

Hawkey, R. (2001). Walking with woodlice: an experiment in biodiversity education. *Journal of Biological Education, 36*(1), 11-15.

Heidinger, C., & Radits, F. (2012). Authentic Inquiry Learning: Students and Scientists "On Equal Terms". In C. Bruguiére, A. Tiberghien, P. Clément, J. Viiri & D. Couso (Eds.), *EBOOK PROCEEDINGS OF THE ESERA 2011 CONFERENCE: Science learning and Citizenship* (Vol. 13, pp. 52-57). Lyon: ESERA.

Hull, D. L. (1997). The ideal species concept - and why we can't get it. In M. F. Claridge, H. A. Dawah & M. R. Wilson (Eds.), *Species, The Units of Biodiversity*: Chapman & Hall.

Kattmann, U. (2001). Aquatics, Flyers, Creepers and Terrestrials — students' conceptions of animal classification. *Journal of Biological Education*, 141-147.

Kattmann, U., & Schmitt, A. (1996). Elementares Ordnen: Wie Schüler Tiere klassifizieren. *Zeitschrift für Didaktik der Naturwissenschaften, 2*(2), 21-38.

Krüger, D., & Burmeister, A. (2005). Wie Schüler Pflanzen ordnen. *Zeitschrift für Didaktik der Naturwissenschaften, 11*, 85-102.

Lederman, N. G. (2007). Nature of Science: Past, Present, and Future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (1. ed., pp. 831-880). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Lindemann-Matthies, P. (2002). The Influence of an Educational Program on Children's Perception of Biodiversity. *The Journal of Environmental Education, 33*(2), 22-31.

Mason, J. (2002). Observing and Participating. In J. Mason (Ed.), *Qualitative Researching* (2 ed., pp. 84-102): Sage Publications.

Mayer, J. (2007). Erkenntnisgewinnung als wissenschaftliches Problemlösen. In D. Krüger & H. Vogt (Eds.), *Theorien in der biologiedidaktischen Forschung* (pp. 177-186).

Mayr, E. (1988). *Toward a New Philosophy of Biology*: Harvard University Press.

Mayr, E. (1996). What is a species, and what is not? *Philosophy of Science, 63*, 262-277.

Mayring, P. (2007). *Qualitative Inhaltsanalyse. Grundlagen und Techniken*. Weinheim und Basel: Beltz Verlag.

Monka, J., Ierodiaconoua, D., Bellgrovea, A., & Laurenson, L. (2008). Using community-based monitoring with GIS to create habitat maps for a marine protected area in Australia. *Journal of the Marine Biological Association of the UK, 88*(5), 995-1008.

Pfeiffer, V. D. I., Scheiter, K., & Gemballa, S. (2012). Comparing and combining traditional teaching approaches and the use of video clips for learning how to identify species in an aquarium. *Journal of Biological Education, 46*(3), 140-148.

Randler, C. (2008). Teaching Species Identification--A Prerequisite for Learning Biodiversity and Understanding Ecology. *EURASIA Journal of Mathematics, Science & Technology Education, 4*(3), 223-231.

Randler, C. (2009). Learning About Bird Species on the Primary Level. *Journal of Science Education and Technology, 18*(2), 138-145.

Randler, C., & Bogner, F. (2002). Comparing methods of instruction using bird species identification skills as indicators. *Journal of Biological Education, 36*(4), 181-188.

Randler, C., & Bogner, F. X. (2006). Cognitive achievements in identification skills. *Journal of Biological Education, 40*(4), 161-165.

Reydon, T. A. C. (2013). Classifying Life, Reconstructing History and Teaching Diversity: Philosophical Issues in the Teaching of Biological Systematics and Biodiversity. *Science & Education, 22*(2), 189-220.

Rieppel, O. (2007). Species: kinds of individuals or individuals of a kind. *Cladistics, 23*(4), 373-384.

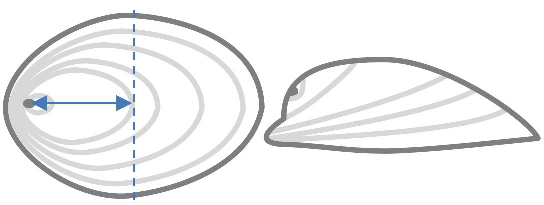
Ruse, M. (1995). The Species Problem. In G. Wolters, J. G. Lennox & P. McLaughlin (Eds.), *Concepts, Theories and Rationality in the Biological Sciences. The Second Pittsburgh-Konstanz Colloquium in the Philosophie of Science*: Universitätsverlag Konstanz, University of Pittsburgh Press

Scharf, S. (2009). Identification Keys, the "Natural Method," and the Development of Plant Identification Manuals. *Journal of the History of Biology, 42*(1), 73-117.

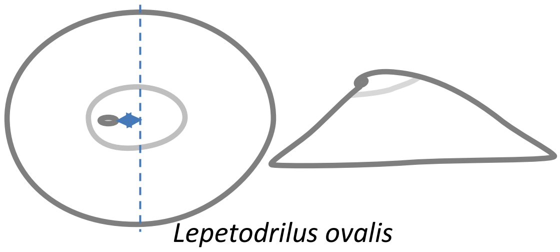
Stahl, D., & Groß, J. (2011). „Was sollen Muscheln mit Zähnen?" – Lernervorstellungen im Prozess der Artansprache bei marinen Muschel. *Erkenntnisweg Biologiedidaktik, 10*.

Appendices

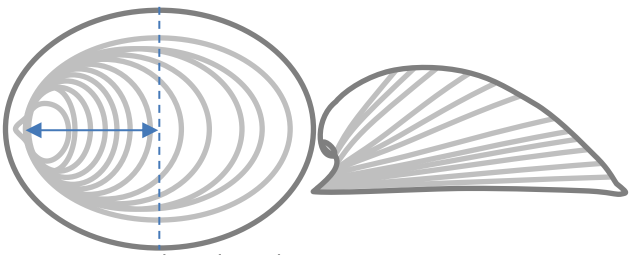
Appendix 1. *Detailed illustrations of four species*



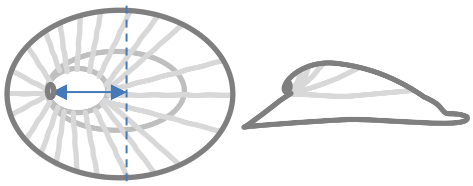
Lepetodrilus elevatus



Lepetodrilus ovalis



Rhynchopelta concentrica



Lepetodrilus pustulosus