Induction as an empirical problem: how students generalize during practical work

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We examined how university students made generalizations when making morphological observations of insects. Five groups of two or three students working together were audio recorded. The results were analysed by an approach based on the work of Wittgenstein and on a pragmatic and sociocultural perspective. Results showed that students rarely made generalizations in terms of universal statements and they did not use induction or produced hypotheses for testing in an analytic philosophical sense. The few generalizations they made of this kind were taken from zoological authorities like textbooks or lectures. However, students used induction when in more familiar contexts. Moreover, when generalizations were analysed in the sense of Dewey, it became evident that students are fully capable of making generalizations by transferring meaning from one experience to another. The implications of these results for using induction and hypotheses testing in instruction are discussed.

Introduction

In science, generalizations are made that apply beyond the actually examined instances. This way of proceeding is called induction. In a general sense all humans have to make generalizations all the time. When we act and talk we deal with the present and the future by using knowledge from the past. In science generalizations are given names like facts, results, conclusions, models, theories, laws and hypotheses. Generalizations are the result of social processes that include various empirical methods (Gould 2000). The empirical methods are emphasized by the scientists themselves in their work, while the social processes are rarely mentioned when scientists present their results (Latour and Woolgar 1986, Knorr Cetina 1999). The social processes are also seldom mentioned in scientific textbooks and in instruction (Duschl 1988, Östman 1998).

Just as in scientific research, great emphasis is put on observation as an inductive method in science education. Systematic observations or the testing of hypotheses in experiments are considered not just as tools to examine questions of truth, but also as methods to help students to learn science content. Hence, laboratory work and practicals in general are seen not only as ways to learn laboratory process skills and how scientific knowledge is produced, but also as ways to learn scientific results (White 1996). In a recent study of teachers’ aims for laboratory work in upper secondary school and in early university education in six different European countries, the most common objective for laboratory work was for students to link theory to practice (Welzel et al. 1998). It is therefore of considerable interest to
understand to what degree students can generalize more theoretical understanding from experiences during laboratory work.

In this paper we examine how university students generalize during practical work and to what degree they use observations for this purpose. We ask what constrains students' possibilities of using their own observations in the making of generalizations during a practical where they are supposed to draw conclusions about insect morphology by observation of pinned specimens. As a background we first present a) how the induction problem has been treated by philosophers, and b) induction by observation as a problem in science education. We then present three different views of how people generalize and give an empirical analysis of how students make generalizations during practical work.

Induction as an epistemological problem

Traditionally in analytic philosophy the basic form of induction has been to infer from a number of instances of A, where A has B, that A always has B. A proposition of the form ‘A always has B’ is called a universal proposition. Hence, from the perspective of analytic philosophy, induction can be viewed as the principle that we use to produce a universal proposition from single instances (e.g. Mill 1965: 330).

Induction in the analytic tradition thus includes at least two problems, namely on the one hand how universal propositions can be verified, and on the other hand how universal propositions can be inferred from instances. Popper (1985) has referred to these two problems as the logical and psychological induction problem respectively.

In analytic philosophy, induction faces logical problems which have to do with difficulties of verification. There is neither any consistent logical principle, nor any principle based on experience, that can inform us about when induction is valid. Popper (1985), in accordance with Hume, argued that universal propositions can never be confirmed, no matter how many verifying instances we observe. On the other hand, Popper argued, it is logically possible to demonstrate that a universal proposition is false. All that is needed is a single instance that does not agree with the proposition. Hence, in a logical sense, Popper thought that universal propositions could only be falsified. Ideally universal statements only survive as long as they are not contradicted by observation and experiment.

Popper also dismissed induction as a psychological principle for inferring universal propositions. Thus, according to Popper (1985: 103–104) induction is used neither for inferring universal propositions nor for testing them:

Hume, at the same time, and in sharp contrast to myself, believed in the psychological power of induction; not as a valid procedure, but as a procedure which animals and men successfully make use of, as a matter of fact and of biological necessity. [...] I disagree with Hume’s opinion (the opinion incidentally of almost all philosophers) that induction is a fact and in any case needed. I hold that neither animals nor men use any procedure like induction, or any argument based on the repetition of instances. The belief that we use induction is simply a mistake.

This means that Popper argued that observations do not unequivocally produce certain universal propositions or generalizations. Universal propositions result from a number of accidental occurrences and may be viewed as guesses, conjectures or hypotheses.
Also Dewey (1991: 128) dismissed induction in the traditional analytic philosophical sense as a route to generalizations:

He [the child] does not begin with a lot of ready-made objects from which he extracts a common meaning; he tries to apply to every experience whatever from his old experience will help him understand it, [...]

A consequence of Dewey’s and Popper’s dismissal of induction in the analytic sense, i.e. as a collecting of neutral observations, is to ask the empirical question ‘How do we make generalizations?’ and ‘How do observations interact with other experiences when we make generalizations?’ This means that we consider induction as tantamount to making generalizations, where generalizations are used in the sense of Dewey (1991: 212), i.e.:

The inherent significance of generalization is that it frees a meaning from local restrictions; rather, generalization is meaning so freed; it is meaning emancipated from accidental features so as to be available in new cases.

Generalizations thereby include not only propositions, but also all utterances and actions that express generalizations in Dewey’s sense.

It is not just the psychological induction problem that needs to be examined empirically, but also the logical induction problem. The practical application of Popper’s solution to the logical part of the induction problem is not a matter of course, which he himself realized. Popper’s solution to the logical problem of induction is mainly a solution to a problem stated in terms of the logic of analytic philosophy and it has little to say of how his epistemology is related to authentic practice:

This logical situation is completely independent of any question of whether we would, in practice, accept a single counterinstance – for example, a solitary black swan – in refutation of a so far highly successful law [i.e. all swans are white]. I do not suggest that we would necessarily be so easily satisfied; we might well suspect that the black specimen before us was not a swan.

(Popper 1985: 110)

Kuhn (1970) compared Popper’s solution to an ideology rather than to a methodology for treating universal propositions. Not even in science can propositions be safely falsified in a strict analytic, logical sense, because it is always possible that a true hypothesis is rejected. The reason is that experiments always depend on a number of conditions and assumptions that can never be completely controlled in the strict analytic, logical, sense (Popper 1968: 50, Kuhn 1970: 13). Hence, the principle of falsification faces the same logical difficulties as verification. When knowledge is treated in the analytic philosophical tradition, there is no accepted way of securing the relation between an observation and a proposition, because every observation is ultimately unique and because every effort to ground our propositions results in an infinitive regress. Our propositions are not based on single neutral observations or essences. Observations can only be made sense of by reference to other experiences as parts of a culture and a language. Hence, falsifications and verifications might need revision later, in the light of additional experiences that may change our frames of reference.

These few examples illustrate the problems that confront induction as a philosophical problem. Induction has even been called ‘the scandal of philosophy’ (Holland et al. 1986: 1). But although induction is difficult to defend philosophically, it can hardly be denied that we perpetually make generalizations in our lives:
But how can previous experience be a ground for assuming that such-and-such will occur later on? – the answer is: What general concept have we of grounds for this kind of assumption? This sort of statement about the past is simply what we call a ground for assuming that this will happen in the future. – And if you are surprised at our playing such a game I refer you to the effect of a past experience (to the fact that a burnt child fears the fire).

481. If anyone said that information about the past could not convince him that something would happen in the future, I should not understand him. (Wittgenstein 1967: §§ 480-481)

According to Wittgenstein (1967) it is not just observations that we use to make generalizations, but also the meanings we share through our language and those practices we participate in. This would mean that generalizing does not only involve seeing a connection between observations and a universal proposition or hypothesis, but also learning rules about what to observe and how to talk and act in relation to observations. And because these rules are social constructions we must learn how to make generalizations from people that are authorities on the specific practice (Wickman and Östman 2001). What allows us to make generalizations then must be analysed empirically in authentic practices. It cannot be decided in an eternal, logical, sense, independently of specific human practices.

Moreover, according to this view, Popper’s distinction between the logical and psychological sphere ignores that in a certain practice both logic and psychology have social dimensions that unite them in a common background as ways of approaching and solving problems. When the purpose is to study induction empirically, it is more fruitful to view psychology and logic as habits and rules for reasoning and action, where these action patterns are integrated with human practices with specific aims. This is a pragmatic basis when examining induction.

**Induction as a problem in science education**

The opportunities for students to make generalizations from observations are constrained by a number of instructional factors. Better knowledge of these constraints is necessary if we want to understand the meaning that students may give to their observations. One important constraint is that students must use socially shared ways of rendering meaning to observations (cf. Bruner 1990). Meaning does not emanate from the objects themselves.

The meaning given to objects in science often differs from the meanings given to objects in practices that students already are part of. Hence, during laboratory work students have to find out what is relevant to observe and what counts as a valid observation from the scientific point of view. They have to differentiate between what counts and does not count in the specific context of the laboratory exercise. Students may have difficulties because they are not able to situate their practical work in a context where observations can be given the meaning expected by the teacher. For example, Säljö and Bergqvist (1997) argued that students could not make sense of a laboratory practical in physics because they did not possess the theories necessary to give meaning to the experimental procedures and results of the practical. Carravita and Halldén (1994: 92) came to a similar conclusion:

... the science learner is expected to discover general schematizations and principles. But, not only are the claims that can be formulated in a classroom based on a very limited range of experience and evidence, but also they will be seen by the students to
be merely a collection of unconnected facts since the connectives – which can only be supplied by those theories the student are supposed to discover – are exactly what is lacking.

This amounts to a paradox, which can only be resolved by studying how students actually make generalizations (Wickman and Östman 2001).

Another difficulty is for students and teachers to use laboratory equipment in a way that give results that can be used inductively to explain theory. Often theory and advanced scientific knowledge are necessary to arrange and interpret observations and experiments. And experiments may go wrong. All these problems of observing create a classroom culture of what might be called pedagogical deception. Students ask the teacher what should have happened instead of studying what really happened (Osborn and Freyberg 1985, Claxton 1991). Teachers, on the other hand, either ‘talk their way through it’ or ‘rig’ or ‘conjure’ to produce desired results from their experiments or demonstrations (Nott and Smith 1995).

Obviously practical demonstrations and laboratory work put great expectations on students' abilities to generalize from observations and experiments. None the less, it is difficult to imagine science education without confronting students with the physical world and opportunities for students to make generalizations that also include real physical objects. So the question is: How do students generalize during practical work?

**Analytical approach**

To see how students generalize during practical work, we will confront the three views presented above about how students generalize during practical work, and ask:

1. Do students use induction in the analytic sense, i.e. do students first make a number of single observations and then extract a generalization to a class of objects? This way of generalizing can be represented as:

   current observations → *universal proposition*

   where the arrow represents the act of generalizing and the part in italics represents the generalization.

2. Do students test hypotheses in the Popperian sense, i.e. do they use different prior experiences to produce hypotheses, which they test against an observation? This way of generalizing can be represented as:

   other experiences than current observations → hypothesis → current observation → *hypothesis verified* or falsified

   However, it should be noted that Popper avoided the word ‘verified’ and preferred ‘corroborated’ instead to stress the temporary nature of generalizations.

3. Do students make situational generalizations in the extended sense of Dewey, i.e. do they try to apply their prior experiences to give meaning to an observation? This way of generalizing can be represented as:

   other experiences than current observations → current observation is given *meaning*.
We will also ask how students can decide what observations count as relevant during the practical and examine to what degree this is a social construction that needs to be learnt from authorities on the practice.

To answer these questions student talk needs to be analysed to see what generalizations students make while talking and how these generalizations are made. This means that the process of making generalizations can be viewed as a learning process revealed through discourse. For such a purpose we use a theoretical, discursive mechanism to analyse the learning process proposed by Wickman and Östman (2001), which combines a view of learning as a social construction with a view that acknowledges a physical world and cognitively and emotionally active individuals.

During discourse we say and do things without hesitation or without asking. In accordance with Wittgenstein (1969), Wickman and Östman say that these utterances or actions 'stand fast' (they are taken as obvious and are not questioned). One example is when students observe bumblebees during a practical in zoology and say, 'bumblebees are hairy' without asking what bumblebees or hairy mean or what they refer to. In a discourse also a number of encounters between people and between people, things and earlier experiences occur when we act or talk. It can thus be observed what encounters (text books, pinned insects, peers, prior experiences etc.) students use when they make generalizations.

Most importantly, during discourse new relations are expressed in talk and action, which make the learning process possible to observe. The relations that are construed by learners can be described as either similarities or differences to what is standing fast. An example from the practical studied in this paper illustrates this. Two students discussing a butterfly:

L: Hair cover? It looks pretty hairy.
M: Really shaggy actually.

Here the students construe similarities between 'butterfly' and 'hair cover' and 'pretty hairy' and 'really shaggy'. Apparently 'hair cover' and 'pretty hairy' and 'really shaggy' are standing fast to them in this short encounter between these students, the purpose of the practice, and a pinned butterfly.

In a similar way also differences confer meaning, without there being a single contradiction. In this encounter with a pinned butterfly the same two students as above discuss the wings of the butterfly:

M: Different colours on the underside and the upper side.
L: Yeah.

The students here construe a similarity between ‘butterfly’ and ‘colours’ and ‘underside’ and ‘upper side,’ but also a difference between ‘colours on the underside’ and ‘colours on the upper side’. ‘Colours,’ ‘underside’ and ‘upper side’ are standing fast in the encounters occurring.

These relations are construed in encounters that involve the teacher’s instructions (they were told to observe certain traits of the insects), and the purposes with the practical. There are also encounters between L and M and their experiences that meet in their discussion. Finally there are encounters with the pinned butterfly. All these encounters – involving encounters between people and encounters with the physical world – can be described from students’ talk and action. Here we
are particularly interested in those encounters occurring while students construe relations, which can be characterized as generalizations.

When a relation is established between what is standing fast, a gap is filled. Hence, for a discourse to continue, gaps need to be filled with relations that stand fast. Moreover, noticing the existence of gaps are necessary for gaps to be filled. But not all gaps are filled. Types of encounters and what stands fast to the participants in the encounter influence the gaps noticed and whether and how they are filled.

Typically people first try to fill the gap with a number of relations. However, the relations construed do not necessarily fill the gap. Such gaps that are left without being filled are called lingering gaps (Wickman and Östman 2001). The only criteria for deciding whether a gap is filled or not are thus if people construe relations that stand fast to them. This means that to see whether a gap is filled or not cannot be determined by an outside epistemology, like that of the observer or a scientist (Wickman and Östman 2001). However, the relations that fill gaps may of course be questionable from an outside perspective (i.e. from the teacher’s or the scientist’s perspective) in an analysis of how gaps are filled. But it must be emphasized that knowledge is always an inseparable part of some human practice and the perspective chosen must always be made explicit (Davidson 1985, Rorty 1991).

**Educational setting**

During a practical students discuss numerous different things and they make numerous generalizations. Hence, from a pragmatic perspective it is necessary to restrict the analysis to those conversations of the students where they discuss topics within the realms of the aims of the practical. The aims of a practice may be described differently by different participants. In this study we take the aims of the teacher as a demarcation line of relevant topics to analyse. These aims were described to the students at the start of the practical. These aims can be seen as the ambitions of the teacher and our analysis can be seen as a description of how students generalize in this light. The teacher’s instructions and aims can be viewed as rules for the lesson.

A major aim of the lesson was inductive. The teacher wanted the students to study the morphology of particular pinned insects by observation, which suits the purpose of our analysis. The parts of the students’ conversations dealing with the morphology of the insects are therefore isolated for analysis.

The practical on the morphology of insects was part of a first year biology course at the university where laboratory work was alternated with lectures. During the practical the students were supposed to study five different insects from four different orders (two different species of beetles, a stink bug, a butterfly and a bumblebee). They were not allowed to ask the teacher questions while doing this. They only received very general instructions before starting. The teacher asked them to find out which orders the insects belonged to and to study in general terms the antennae, wings, mouthparts, compound eyes, ocelli and hair cover of the insects. They were asked to see if there was anything special about the different parts. Regarding the mouthparts they only had to look to see if they were ‘sucking’ or ‘chewing’. They did not have to put names on the different mouthparts. They were encouraged to look for help in the literature available at the laboratory. The teacher also encouraged the students always to reflect on the relationship between
structure and function when studying animals. He also encouraged them to draw the animals under study. After an hour the teacher summed up the students’ observations in front of the whole class.

Student talk was audio recorded with a microphone placed on their laboratory desk. Actions of students that were inferred from sounds and from what students said are given in parentheses in excerpts of student talk (translated from Swedish). We attended the practical during the start to get a better idea of what students were doing.

The students worked in groups of two or three together. Here we report the discussions from five such groups of students. Recordings from each group represents approximately the first 20 minutes of their discussions, during the time which they examined two or three different insect specimens.

**Did students use induction in the analytic sense?**

Did students use induction in a catholic analytic sense; that is, did they infer from a number of examinations of an organ A, where the organ always had the quality B, that the organ A generally has the quality B? A first step to see if students make generalizations in this way is to examine all those statements by students that by an inclusive interpretation could be recognized as universal propositions, i.e. statements like ‘all butterflies have antennae’ or ‘they have two wings’ or ‘ocelli look like this’. It can then be examined to see if these statements were the result of ‘analytic induction’.

Universal propositions even in this inclusive sense were relatively rare in student conversation. Three types of universal propositions occur (which henceforth will be referred to by their roman numerals):

I. Universal propositions that were established in an encounter with an authority.

II. Universal propositions that were established in a single encounter with a physical animal object.

III. Universal propositions that were established in repeated encounters with physical animal objects.

**Universal propositions of type I**

Universal propositions of type I are generalizations where students construed a relation between the observed insect and a generalization that they did construe in a manner derived from an encounter with what other people say or write. This is the most common of the three types of universal propositions. In all, 17 such statements were made by all the five groups of students. These generalizations involved a relation between on the one hand a group of insects and on the other hand what organ they possessed, what the organ looked like or how it could be used. Examples of such generalizations were (Arabic numerals are used for generalizations for reference):

1. They shouldn’t look like this, after all (about the observed insect). They’ve got an eye on each side, don’t they? They usually do, to be sure.
2. Crustaceans have two pairs and insects have one pair (of antennae).
3. These of course suck . . . nectar and stuff.
4. But these ocelli, the small eyes.
5. Yes it’s got two pair of wings. All have that.

In these statements the students made generalizations by construing the following relations:

1. Similarity: they – an eye on each side.
3. Similarity: these – suck nectar and stuff.
5. Similarity: all of them – two pair of wings.

In none of these cases was a generalization a result of students extracting a common meaning from a number of examined objects. Instead they used meanings in what was based on earlier encounters and they tried to use these meanings to construe relations in the encounter with the organs of the pinned insect. This means that students tried to use generalizations that are part of the zoological practice and that they tried to put these generalizations to work in the encounter with the pinned insect. In this way the pinned insect could be fitted into the zoological language-game. Generalization 1, for example, occurred in the following conversation between the students S and V:

S: But how in hell is he constructed? (Laughter)
V: Want me to hold?
S: No wait, I’ll just zoom him in. Why (laughter) … where is the top and where is the bottom of the head?
V: What, top and bottom?
S: But hey, look at it. He’s got one eye at the top and one at the bottom, you know. He must have turned his head or something. He can’t look that way, after all.
V: Well … but he did that.
S: They shouldn’t look like this, after all. They’ve got an eye on each side, don’t they? They usually do, to be sure.
V: Yes, but he did turn his head.
S: Yeah.

From this excerpt it is evident that the generalization was something that they were already familiar with and that the generalization was used to construe relations between the pinned insect and the top and the bottom of the head. These relations these students used later for finding the ocelli, which according to a diagram were on the top of the head. In a similar way the other universal propositions of type I were inferred and used.

**Universal propositions of type II**

Universal propositions of type II were construed in encounters with a pinned insect. These generalizations established a relation between a group of individuals (a class) and the observed pinned insect. Only four such statements occurred, and in all cases the students referred to the unspecified class ‘they’:

6. But they’ve got these … claw like things. (Similarity: they – claw like things).
7. They’ve got compound eyes and … (Similarity: they – compound eyes).
8. They’ve got their . . . such . . . (inaudible word) on the belly. (Similarity: they – something on the belly).

9. They are also hairy on the thorax. (Similarity: they – hairy on the thorax).

None of these relations were the result of students examining several individual insects. Instead they generalized to ‘they’ from a single individual. There was nothing to suggest why they used universal propositions of type II in precisely these cases. The students did not say which individuals were included in the class ‘they’. One possible interpretation could be that ‘they’ referred to other insects with the same name as used by the students to refer to their pinned insect, e.g. beetles, or that ‘they’ referred to the particular species of insect or insects in general or to a larger organ like legs etc. However, because the students did not express explicitly the class they referred to, there could hardly be any agreement between the students. Probably this type of generalization was only a way for students to vaguely acknowledge that what they observed on their pinned specimen also could be observed on other specimens with a similar appearance.

### Universal propositions of type III

Universal propositions of type III were generalizations that referred to repeated encounters with the same quality in observed animals. Three such cases were found:

10. The things they come off. They [the pinned insects] are so extremely sensitive.

11. They’re all [the pinned insects] a bit rickety but . . . this one I think will have almost everything.

12. K: They’ve got their . . . such . . . (inaudible word) on the belly. L: Didn’t the crustaceans have that too? K: Did they? L: No, but the crustaceans did have that on the belly at least. Every crayfish we dissected had that. It was a damned problem to you when . . .

All these three cases concerned something that a class of individual animals had in common and that prevented the students from observing the animal. The generalizations in the above cases meant that the students used the following relations:


It is not clear from cases 10 and 12 in which order these similarities were construed by the students. It cannot be inferred with certainty that the students used analytic induction by repeated encounters. Each generalization could just as well have been made in a single encounter. For example, a single encounter with an insect where a body part came off together with the students’ prior experiences of fragile materials could be enough to make a student careful when touching pinned insects. But in case 11 it may seem as if students used something that is reminiscent of analytic induction by repeated encounters:

C: This one is really, although it had no head.
B: Oh no.
(Both are laughing)
C: I thought there was something missing.
B: ( Gets another insect) They’re all a bit rickety but ... this one I think will have almost everything.

Nevertheless, even though we suppose that analytic induction was the process also yielding generalizations 10 and 12, analytic induction seemed to be rare. However, it should be noted that none of these cases involved a use of scientific language about organ qualities. They rather concerned qualities that prevented students from Construing relations that could have given meaning in the encounters with the insects as parts of a zoological practice.

There are reasons to believe that generalizations 10–12 were not the result of collecting observations as such without reference to a practice or prior experiences. A pragmatic interpretation of these actions is reasonable, namely that students observed the insects in light of the aims of the classroom practice, i.e. to see how insects were built. Students therefore observed (treated) each individual from this purpose and judged their suitability from this purpose. A flimsy insect was of course highly unsuitable for the purpose of this practical, which meant that a difference was construed between the individual and its suitability for observation. However, although these generalizations could not be said to be examples of analytic induction in the strictest sense, they represent cases of generalizations beyond single instances.

**Overview**

It thus appears as if all the universal propositions that students made were a result of pinned insects being observed in the light of the aims of classroom practice and also that meanings from prior encounters with the zoological authorities were used to construe relations in encounters with the pinned insects. Interestingly, the closest students came to induction were when they judged qualities of the animals that were not of primary scientific interest.

**Did students test hypotheses?**

The relatively few generalizations formulated as universal propositions imply that students themselves rarely made statements that could be described as testable hypotheses. In a Popperian sense all the universal propositions made by students could be viewed as hypotheses, i.e. generalized relationships between two qualities (e.g. ‘all swans are white’) that could be tested in terms of verification or falsification. To this category could also be added explicit gaps (i.e. questions or hesitations) made in the form of universal propositions. To the list of universal propositions already mentioned the following explicit gaps regarding generalized relations can be added:

13. Or should it always have ... (antennae)?
14. And then we should check if they have those ocel ... , ocelli or whatever they were called.
15. Or do they have to have antennae?

Interpreted as hypotheses they could be viewed in the following way:

13. That class always has antennae.
14. They have ocelli.
15. They have antennae.

It can then be asked if these different kinds of universal propositions (both relations and explicit gaps) are tested as hypotheses in the sense above by the students, i.e. if they examine if they are true or false by observing the pinned insects. That is, are those universal propositions that look like hypotheses also used as such? Do the students try to verify or falsify their universal propositions?

If students use universal propositions as hypotheses, then their universal propositions ought to be followed by efforts to verify or falsify these propositions. A falsification or verification implies that the students construe a relation between the universal proposition (the alleged hypothesis) and observations, which amounts to another universal proposition, whereby the prior universal proposition is accepted or rejected.

In student talk the universal propositions was followed by the following situations (henceforth referred to as situation A–C):

A. The universal proposition was falsified by observations.
B. The universal proposition was verified by observations.
C. The universal proposition is not followed by observations.

In those cases where universal propositions were falsified or verified by observations, the universal propositions were generalizations that were construed in encounters with what other people (zoological authorities) had said or written (generalizations of type I). Typically such a generalization was used to see whether the pinned insect had a certain organ or to see what the organ looked like on the pinned insect. When the pinned insect had an organ that they found to agree with what zoological authority had stated, the encounter was classified as situation B above, i.e. in an analytic sense the observations would seem to have verified a hypothesis. But sometimes the students could not find the organ in question. This kind of encounter was classified as situation A above, i.e. in a strict Popperian sense the apparent hypothesis was falsified and should be rejected. But did the students really treat their statements in this way?

Did students falsify hypotheses?

In situation A students usually stuck to their universal propositions but rejected their observation. The excerpt given earlier about the top and bottom of an insect head is one example. Instead of rejecting the convention of what is top and bottom, the students used an *ad hoc* explanation, namely that their insect had turned its head. Another example is the following discussion between two students:

V: But I see only one pair of ... wings.
S: Mm, I also saw only one pair of wings but there must be another pair.
[They speak about other things for a while.]
S: Look if you can see more wings.
V: No more wings.
S: Noo. After all, there should have been. But heavens, I see only one pair of wings.
V: Mm.
S: They’re dusty too. Poor thing. Yeah but we have at least looked at the wings.

Also in this case it can be seen that students gave *ad hoc* explanations in not rejecting the generalization that the pinned insect belong to a class of insects
with four wings. After all, the insects were dusty too, and hard to observe. So the interpretation that the universal propositions of these examples are hypotheses, which students tested, is difficult to defend. Instead the students seemed to use the authorized generalizations as something that can be used to make relevant observations of the pinned insects. Generalizations were used to construe relevant relations that can be extended to the pinned insects.

However, students did not always defend the universal proposition they construed in encounters with zoological authorities when they encountered conflicting observations. Although they never rejected a universal proposition in encountering an observation, there was one example where three students became uncertain during a discussion concerning the general applicability of the universal proposition:

S: I see no antennae, but I know that they have antennae.
F: Yes, they should have that.
S: They should have ...
F: He said so during the lecture.
S: Did he talk about butterflies on ...
F: Then he said ... yeah some like for example butterflies have antennae with smells and blah blah blah ...
S: Okay. They’ve got to have antennae.
[They speak about other things for a while.]
S: Does it have one or two pairs of antennae?
F: I don’t know. Ours had no antennae, did it E?
E: What?
F: Antennae?
E: Teeth? [The Swedish words for ‘antennae’ (antenner) and ‘teeth’ (tänder) sound similar]
(They all laugh)
E: Didn’t you check if it had teeth? (Laughter)
S: Open your mouth!
F: Antennae.
E: Antennae. Yeah, I will check that ... I don’t know. Teeth. Yes it’s got four teeth.
F: No ... but it doesn’t look like this.
E: No ... but ... honestly I see no antennae on this one. Or do they have to have antennae?

As can be seen this case did not represent an instance of falsification. Instead an explicit gap appeared between ‘they’ (butterflies?) and antennae that the students did not succeed in filling. They did not construe another universal proposition stating that ‘they’ do not have to have antennae. It is as if the students could not decide if they had incomplete authorized knowledge of antennae or if they did not know what to observe. Hence, there was no case where students used universal propositions as hypotheses that they tried to falsify.

**Did students verify hypotheses?**

Neither in situation B did students treat universal propositions as testable hypotheses. A confirming observation did not result in students making a new universal proposition. Instead students construed a relation between the individual pinned insect and an organ. Their conclusion was stated only in terms of the observed individual. One typical example is this excerpt from two students that were studying a butterfly:
The relation

16. Similarity: they – only one pair of antennae was linked to prior experiences, probably with a zoological authority according to which insects have only one pair of antennae. This relation helped students to construe the following relations:


Hence, students did not use relation 16 as a hypothesis that was verified by observations, because they did not make a new universal proposition after the generalization 16. Instead students used meanings from relation 16 to make meaning in the encounter with the individual pinned insect.

The universal proposition was not followed by observations

Many of the universal propositions were not followed by students making observations on their own. They were statements that were not tested in any sense and thus they were not treated as hypotheses by the students. All universal propositions of type II and III and about half of those of type I were of this kind. Examples of type I were the cases 3 and 5 given earlier.

Conclusion

Hence, the universal propositions students made were not used as hypotheses and were not generally tested against observations. In conclusion then, it seems as if universal propositions were neither the result of an inductive process, in the analytic sense, nor were they used as hypotheses in the Popperian sense that were tested either for falsification or for verification. Only in a very inclusive sense were students seen to use induction, i.e. they were capable of making a generalization from a number of observations only when the meaning of these observations stood fast in relation to an everyday language-game and a common sense use of words. It was not possible when generalizations had to make that were part of the zoological language-game.

Instead it seems as if the vast majority of universal propositions could better be explained as generalizations in Dewey’s sense. The meanings from old encounters are used to make meaning in new encounters. As far as universal propositions of type II are concerned, students generalized simply by using ‘they’ about the observed insect. But usually a generalization was a way of using encounters with zoological authorities to situate the encounter with the observed insect in the zoological practice. The generalizations from authorities decided what was relevant to look for and an aid in making sense of observations. Apparently it was a way of learning to act toward real insects as parts of a zoological practice.

It can be concluded that students realized their limitations as observing zoologists. Students realized that they might not understand what they saw, because
they did not recognize the organ in all its different shapes and contexts. Two students expressed this clearly in the following excerpt, where they discussed whether their beetle had ocelli:

B: But these ocelli, the small eyes.
C: That's right. What did we write about where they're placed roughly exactly?
(Turning over pages)
B: Yes, they usually are placed ... I think that it’s like just on the front of the head if you check ... between the compound eyes.
C: I see ... yeah it’s there. It is not placed inside; it’s placed on the side of. Okay.
B: Sometimes I become so dizzy in my head when I move ...
C: Mmm.
B: Nooo ... I can’t see any.
C: It's so tedious. As soon as you turn it around, you have to adjust it again. I can’t see any of those either.
[They talk about other organs for a while.]
B: We don’t see the ocelli anyhow, but maybe we don’t really know what we should look for.
C: No.

**Generalizations in an extended Dewian sense**

_Situational generalizations_

As was mentioned earlier, it was unusual for students to construe relations that could be described as universal propositions. Most of the students’ statements were restricted to a specific insect individual and its appearance. A few examples of such statements are:

18. It’s got two small sticks sticking out.
19. And then you see the mouth yeah.
20. He's so hairy.
21. This one’s got such real chewing jaws.
22. Then it’s got legs.
23. I see the eyes.
24. It seems to have four wings then. Two large and two small.

But although these statements cannot be seen as universal propositions, they can be seen as generalizations in Dewey’s sense, i.e. the student ‘tries to apply to every experience whatever from his old experience will help him understand it’. All the words that were standing fast for the students in this encounter (like ‘legs’, ‘chewing jaws’, ‘eyes’ etc.) represented words that had meaning to the students from old encounters and that were given new or extended meaning in the new encounter.

This also means that statements in the singular are to be regarded as generalizations. Just like statements in the plural, meanings are carried over from one situation to another. The overwhelming majority of statements that the students made were about currently observed insects. One example is this dialogue, where two students used meanings from their old experience to make meaning of a pinned beetle:

S: Check the shell, it’s pretty cool actually. Shell ...
[They speak about other things for a while.]
V: But it’s all rugged.
S: Yeah, it’s not at all that kind of smooth as you imagine it would be, but it’s more really like this . . . ‘rumligt’ [an invented word, impossible to translate].

Here ‘shell’ obviously was standing fast from old encounters and the students used the word without hesitation in the encounter with the pinned beetle. In the encounter with the magnified ‘shell’ they construed a number of relations to the ‘shell’ that were new:

27. Difference: the shell is ‘rumligt’ – smooth as you imagine the shell.

Students used meanings related to all these everyday terms to construe new relations among them that made meaning in the encounters with the ‘shell’ of the beetle. The meanings of these old words were generalized to include also this encounter with the beetle. In this way also meanings of zoological terms were expanded, without students using hypotheses or making inductions in an analytic sense. The excerpt below demonstrates when they generalized meanings in an encounter with ocelli on a picture to an encounter with their pinned insect:

V: The eyes have to join down there. They couldn’t join up there for sure.
S: No, they join down there because up there are these three . . .
V: Yes, it’s those that you see here (looking at picture). What is it little wasp?
S: Wrong side (laughter). Check if you see those three eyes they . . . may have.
V: Yeah, I thought I would see them.
S: Whatever they were called that I didn’t remember.
V: Ahh, now I hit the lamp.
S: It’s called ocelli.
[They look at other organs for a while.]
V: Yes there, look there, there you see them. The three holes. Do you see them? Or . . . between the eyes.
S: I see something orange.
V: Yes, something orange between the eyes. One, two, three dots.
S: I see.
V: Do you see them?
S: Yes.

Because they did not say that all ocelli look like this, they could hardly be said to have learnt that all ocelli look like the observed ones. But they did learn that ocelli might look in the way they describe. They generalized the meanings of the picture to encompass a real insect. This generalization implies that the following relations were fixed in relation to the observed ocelli:


The students could use these relations in future encounters. That is, despite the fact that students did not use hypothesis testing or induction in an analytic sense, this did not mean that students did not learn anything that has more general meaning during this practical. Students learned what a number of different organs might look like on different real insects.
Generalizations and contingencies

Making meaning and hence generalizing from one encounter to another was dependent upon the precise encounters occurring. This process was a complicated interaction between the background of the students and old experiences, i.e. what students brought to the laboratory and how these experiences interacted with the aims, texts, laboratory materials and other artefacts. It is manifested in speech and action how students construed meaning in relation to the observed organs of the insects. In this discourse a number of contingencies occurred that influenced the exact meaning construed. A comparison between the four groups of students that observed a bumblebee gives an idea of the range of possible meanings. The following dialogues concerning the wings of bumblebees were recorded:

**Group 1**

S: Hey you, check these wings. It’s something exciting with these ...  
V: Mm.  
S: ... wings. Do you see that ... that this part kind of ... is he in focus now?  
V: No, he’s not now he’s out of focus. The other way. There he’s in focus. Just a little bit. They’re transparent. And there’s something that stands out. Is it?  
S: Yeah, exactly. Up, up, up against the body so to speak there’s like by each side a flap up.  
V: Yeah, that’s right. What is it?  
S: What is it? Should it be like that or has it only become like this on this one?  
V: Yeah, that’s a good question.  
S: Since both of them are like that, you kind of thought that it maybe was something that should be like that.  
V: Yes. But probably it is. But I see only one pair of ... wings.  
S: Mm, I also saw only one pair of wings but there must be another pair.  
[They speak about other things for a while.]  
S: Look if you can see more wings.  
V: No more wings.  
S: Noo. After all, there should have been. But heavens, I see only one pair of wings.  
V: Mm.  
S: They’re dusty too. Poor thing. Yeah but we have at least looked at the wings.

**Group 2**

I: Wings, don’t know what to comment. Yes, answer yes. They have wings kind of. Should we write the number maybe? It seems to have four wings then. Two large and two small.  
H: Yes.

**Group 3**

B: Hey, the number of wings on that one [a butterfly], we didn’t see that.  
C: We didn’t check that.  
B: This one’s [bumblebee] got one pair of wings anyhow.  
C: He didn’t write that we should check look at either.

**Group 4**

L: Yes the greatest difference is like really the wings on this one [compare a bumble bee with a butterfly].  
M: Yeah ... transparent.
It is evident that the different groups noticed different things about the wings of their respective bumblebees. Group 1 and 3 only saw one pair of wings. Group 1 questioned this in light of old experiences, but Group 3 did not. Group 2 saw two pairs of wings (two large and two small), while Group 4 did not count the wings at all. Group 4 only noticed that the wings were transparent. Group 1 also saw that the wings were transparent, but they also noticed flaps on the wings.

That the students of these different groups construed different relations in this situation must depend on a number of contingencies. An important difference was the different bumblebee individuals they observed. The number of wings, which are four according to the zoological discourse, may be more or less easy to see on different individuals. But it is also possible that the students produced different meanings for what they observed. The two small flaps that Group 1 saw could have been the hind wings, which are much smaller than the front wings. Group 1 did not succeed to construe a relation between the pinned bumblebee and four wings. An explicit gap lingers in the encounter with the pinned bumblebee. They did not succeed to situate this generalization in the classroom practice of observing the morphology of pinned insects. Group 3 on the other hand did not question that their bumblebee had only two wings. Old meanings and old experiences of wings did not suffice for these students to even notice the gap that Group 1 noticed.

It is interesting to notice that students could apply some sort of zoological logic in a few cases, e.g. symmetry, as was the case with the flap. But often authorized generalizations could not be taken far. The authorized generalizations that bumblebees should have four wings may be useless when students encounter a bumblebee. A vast number of generalizations are needed to make meaning in a practice.

What made it difficult for students to generalize?

Before students can make more extensive generalizations about insect morphology it is clear that numerous relations must be construed in encounters not only with old experiences but also with real insects. Students also need to meet people that are members of a zoological community of practice, who would help them to make meanings about where insects and insect organs are used for specific purposes. These meanings and purposes are not self-evident to students by simply encountering insects in isolation.

In any practice or language-game a number of rules need to be learnt about what counts and what does not count as appropriate or relevant. Such generalizations cannot be constructed simply by analytic induction or by hypothesis testing. Moreover it represents an insolvable problem for students to relate different looking insect organs with the correct insect groups simply by observation. All such relations can only be given meaning in relation to rules of thumb or evolutionary theory.

An insect part that zoologists give the same name may look very different to a student. So how could they realize that they should be given the same name? Several students called the elytra of beetles ‘shell’, and they did not recognize them as wings. Organs may also look different in different individuals. One group simply concluded that their insect had no antennae, without discussing the possibility that they may be broken. It can also be difficult to know what parts really belong to the insect:
Without authorized zoological meanings directly applicable in a certain encounter, it may thus be impossible for students to see what belongs to the insect, what are idiosyncrasies of a certain individual, what systematic group a certain insect design is associated with, and what counts as a specific organ. Moreover, a negative observation, i.e. when an insect has an organ missing, may result because the students do not know what to look for, as a student made explicit in an earlier excerpt (‘We don’t see the ocelli anyhow, but maybe we don’t really know what we should look for.’). The authorized meanings necessary to make sense of observations are an integrated part of the zoological practice that is the result of centuries of encounters between zoologists and insects. The opportunity for students to interact directly with an authority on zoology to discuss the relations they construe thus seems a necessary ingredient for the making of a zoologically communicable meaning out of this chaos of possible impressions.

Concluding remarks

During this exercise students rarely made generalizations in terms of universal statements. Most statements were about the individual insect at hand. Moreover, the generalizations students made about insect morphology were only produced by something reminiscent of induction when they made observations that were part of an everyday language-game. Neither were the generalizations used as hypotheses for testing. Typically generalizations were taken from zoological authorities like textbooks or lectures. This was the case, although this was a simple laboratory exercise that was performed by university students with high marks from upper secondary school. This reliance of students upon authorities is in line with what other researchers have observed in school classrooms (Osborn and Freyberg 1985, Claxton 1991).

However, our conclusion deviates from these earlier studies on other points. We do not see that this means that these students were incapable of making generalizations on their own. Neither do we see the dependence on authorities as alarming. We see this as an inevitable consequence of meaning being inseparable from its sociocultural background.

One remedy, for the problems encountered here would be to teach students so-called process skills or cognitive skills, so that their inductive capacities would be enhanced (e.g. Harlen 1985, Adey and Shayer 1994, Lavoie 1999). From a Popperian view it might seem that the teacher should train the students to state
bold hypotheses and to teach them how to falsify these, because in this view ‘the
teacher’s main task is to help students to discover and eliminate their mistaken
ideas and specific limitations as quickly as possible’ (Swann 1998).

However, judging from our study, such remedies could only have limited
effect. Many of the problems that students had in making generalizations could
not have been solved only by improving the abilities of students to eliminate
mistakes, identify variables, or by using larger samples. The problem was that
students did not know what counts in the zoological language game. Hence, as
seen from our perspective, the teacher’s task should be to help students to see the
relations of the zoological practice by employing encounters where things stand
fast in communication between students and teacher. They need to be invited to a
new way of talking and acting towards insects. By taking this role the teacher can
take the student’s development further than the student was capable of on her/his
own. Hence, the results of this paper can be seen as an explication of Vygotsky’s
zone of proximal development (Vygotsky 1978: 86).

In this respect it is particularly interesting that students were capable of
induction about the suitability of insects for studying. Obviously students could
make generalizations from single instances and probably they are also capable of
testing hypotheses. However, our results suggest that this is only possible when the
words and actions they use are already standing fast in the specific encounter.
They can then establish a new relation between them, that may extend beyond
examined cases and that may be tested like a hypothesis. When the students say
that the pinned insects are extremely sensitive, the meanings of pinned insects and
extremely sensitive are standing fast in the kind of encounters that occur in the
classroom. However, if they were to test a hypothesis like ‘all beetles have
two antennae’ neither beetles nor antennae would stand fast to them. It would
be impossible for them to test such a hypothesis without further reference to
authority.

Still, learning by hypothesis testing and by practicing skills of observation as
such, is often recommended for science teaching, even at primary school level (e.g.
Harlen 1985). Students are encouraged to suggest what will happen in experiments
and also to propose hypotheses of why they think their suggestions will happen.
The students’ hypotheses are then compared to the actual results. Although ap-
parently well-controlled experiments are done, students often fail to accept the
scientific explanations given (see discussion in Solomon 1992: 28–31). They do not
falsify the hypotheses they were asked to produce even though the observations
seemed to show that their hypotheses are false.

Applying the results of this study, it is not surprising that hypothesis testing
does not necessarily result in learning. An old way of making meaning does not
lose sense because it can be shown as false in a single and often strange situation.
As has been argued earlier people do not make meaning in this way, and moreover,
they do not master all scientific relations necessary to make such a judgment. To
be able to question ideas, we first need to put fast some fundamental relations as
parts of a language-game (Wittgenstein 1969), a process that often proceeds in
small and time-consuming steps (Wickman and Östman 2001).

Finally, it is again necessary to emphasise that students did learn a lot about
insects and also were able to generalize. This is evident when generalizations are
seen in Dewey’s perspective and not in the analytical tradition. Normally students
go from one experience to another, taking meanings along with them. Students
examine how the experiences they made in one encounter applied in another encounter. In this process all sorts of experiences were used to make sense of the insect in light of zoological authorities. By this process students generalize by creating a new range of expectations. They expand their repertoire of acting and talking in the zoological language game by adding additional aspects or relations to for example antennae in new encounters.

Although the practice of so called process skills like inductive reasoning or hypo-deductive reasoning are a central part of meaning making in the scientific community, it is not the only way. There is long way to the construction of new scientific ideas that are rarely documented in science (Latour and Woolgar 1986). Our study shows that the same applies to students learning science.

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References


