1 THE ROLE OF CONCEPTIONS, METAPHORS, AND ANALOGIES IN STUDENTS' UNDERSTANDING OF SEEING

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Abstract

For more than 30 years, students' conceptions have been perceived as an important factor to describe how students understand scientific phenomena. To understand abstract phenomena, metaphors and analogies are seen as fundamental by the theory of experientialism. The aims of this study are to investigate 1) whether explicit mentioning of students' individual conceptions, metaphors, and analogies is fostering understanding of vision and perception, 2) the extent to which metaphors and analogies are helpful, and 3) How different ways of understanding influence the success and retention of conceptual reconstruction.

Three groups of students (N = 217) were compared: individual conceptions were considered and reflected upon in the first group, while the second group learned with the same materials irrespective of their individual conceptions, and the control group had no instruction concerning vision at all. Students' everyday and scientific conceptions were tested before and after the instruction and three months later. The metaphors and analogies students drew, commented, or reflected using worksheets were analyzed by qualitative content analysis.

In most cases the results of the students were significantly better if their individual conceptions were considered and reflected upon. Notably in this study, abstract conceptions were only reconstructed if the individual conceptions were explicitly mentioned. The interpretation of students' metaphors and analogies shows that they can be the key to successful reconstruction of abstract conceptions, if explicitly reflected upon.

1. Introduction

Over the last 30 years the role of individual conceptions in understanding has been intensely discussed in biology education (Duit, 1995; Kattmann, 2007). Metaphors and analogies have been mentioned as a basis for conceptual understanding of abstract phenomena (Lakoff & Johnson, 1997; Gentner et al., 1997). Therefore, metaphors and analogies are not just seen as linguistic or rhetoric phenomena but as fundamental for thinking (Lakoff & Johnson, 1997; Schmitt, 2005).

In this study, the biological topic of vision and perception is chosen to examine conceptions, metaphors, and analogies that may empower students to reach better scientific understanding. Some implications for the design of learning environments considering metaphors and analogies are discussed. The topic of vision allows us to examine a broad spectrum of conceptions that are differently understood due to their sources:

- physical conceptions that are based on direct experience, e.g. the *role of light*
- abstract conceptions of phenomena that cannot be experienced and have to be understood imaginatively by using metaphors or analogies, e.g. the *relation between object and eye* or the conception of an *image* that is generated in the process of seeing
- abstract and epistemological conceptions which have also to be understood imaginatively, but in addition have epistemological significance, e.g. the so called *everyday realism* (Gropengießer, 2001) – the conception that we are able to see the world as it really is – in contrast to constructivist ideas

This study focuses on three research questions:

1. To what extent does instruction that explicitly considers individual students' conceptions, metaphors, and analogies support conceptual reconstruction?
2. Which metaphors and analogies foster or hinder students' understanding of the process of seeing?
3. How do different ways to gain understanding – by direct experience or imaginative mapping – influence the success and retention of conceptual reconstruction?

To investigate these questions different learning environments were designed that either allow direct experiences or use typical metaphors and analogies and ask students to reflect on their conceptual use.

2. Theoretical background

2.1 Constructivist perspective on learning

In this study, thinking and learning are understood from a constructivist perspective, i.e. conceptions are constructed based on perceptions. These conceptions are tested in everyday situations and if they are viable they are affirmed. Learning environments should enable students to scrutinize their conceptions and possibly (re)construct them situationally, actively, and self-directedly (Duit, 1995; Reinmann & Mandl, 2006; Riemeier, 2007). These basic conditions have to be considered for the design of learning environments.

2.2 The theory of experientialism – A theory of understanding

The theory of experientialism explains how understanding takes place. It describes the sources of understanding. The main point is that understanding is experience-based. In some cases, direct understanding is possible because we can make experiences. Concerning the process of seeing, students experience that they only see objects in a room if there is light. The conceptions that are generated by those direct experiences are called embodied schemata. In contrast, abstract phenomena that cannot be experienced have to be understood imaginatively: the embodied schemata are used as sources that are mapped on the abstract phenomenon in order to explain it. Doing this they are used as metaphors or analogies. What happens between the eyes and the object cannot be experienced in the process of seeing, so students have to use metaphorical or analogical mapping to understand this process (Figure 1).

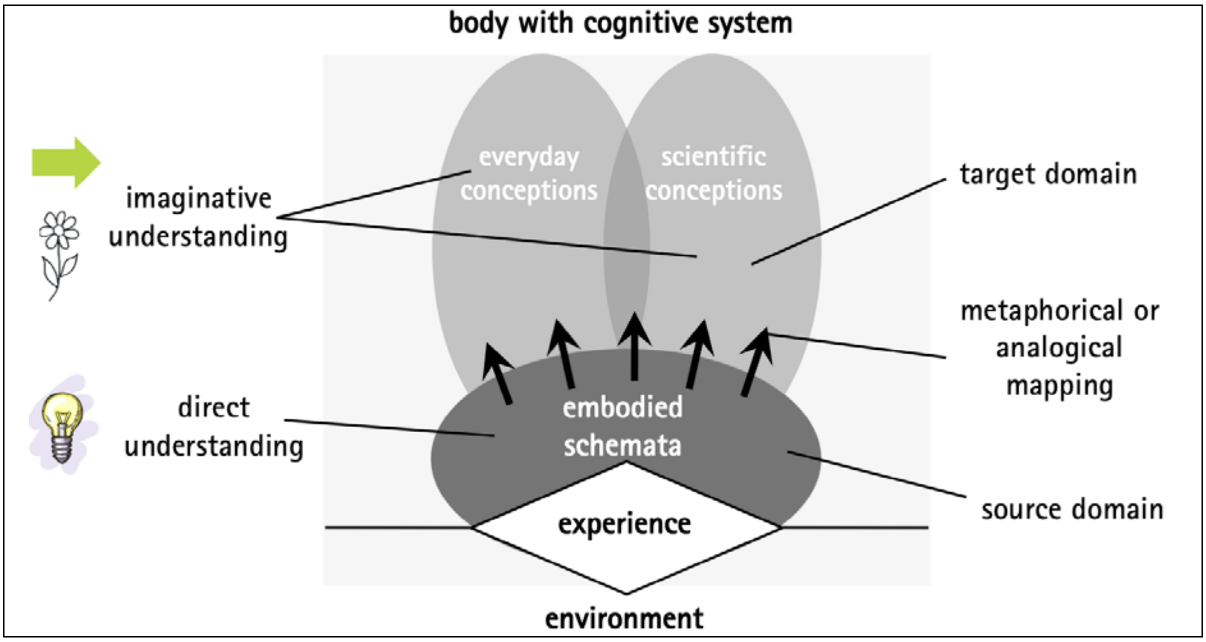

Figure 1. The theory of experientialism (based on Gropengießer, 2007, p. 112; the bulb symbolizes the *role of light*; the arrow symbolizes the *relation between object and eye* and the flower the conception of an *image*).

One common metaphorical schema used by students to explain this process is the start-path-goal schema (Figure 2). It is even used among university students' science textbooks (Campbell et al., 2003, p. 1276). This schema emerges from the experience that we start at one point to get somewhere, cover a distance, and then finally reach our goal (Lakoff & Johnson, 1990, 1997). Another example of abstract phenomena that make imaginative understanding necessary is the question of what is transferred into our eye or brain. Many students hold the conception that an *image* of the object arises in the eye (on the retina) or/and in the brain (Figure 3). Here another basic experience is used as a source domain: seeing oneself or another object in a mirror.

Lakoff and Johnson (1997) do not differentiate between metaphor and analogy. In this study, however, a distinction is necessary. The metaphorical mapping of a source domain on a target domain is happening unconsciously. Metaphors can be reflected and then become an object of metacognition. In contrast, the term "analogy" is used to mark that the mapping process is reflected upon, and we consciously use a specific source domain or specific terms to explain a target domain.

Some conceptions have epistemological character and are therefore affecting other conceptions. They provide a basic framework for these other conceptions so that conceptions that do not fit in this frame are unconsciously excluded. Therefore, the framework affects the conceptual understanding of a domain (Lakoff & Johnson, 1997). One example concerning the process of seeing is the conception of *everyday realism*: we perceive the world as it really is. In many cases this conception correlates with the metaphor of an *image* of the flower that is generated in the process of seeing. According to a constructivist perspective this conception is not seen as a scientific one.

2.3 Conceptual reconstruction

A way to reconstruct conceptions from everyday to scientific conceptions is described by the theoretical framework of conceptual change (Posner et al., 1982; Strike & Posner, 1992). The term "everyday conceptions" describes conceptions which are constructed in everyday situations and which are mostly not corresponding to scientific ones. The reconstruction of metaphors and the reflective use of analogies are perceived according to conceptual change as well. Strike and Posner (1992) describe four phases that enable students to reconstruct their conceptions: students have to be dissatisfied with the explanatory power of their recent everyday conception and the scientific conception has to be understandable, plausible, and fruitful. This constructive process is not seen as a total and rapid change from an everyday to the scientific conception. To mark this the term conceptual reconstruction (Duit, 1999) is used and the possibility to choose between everyday and scientific conceptions in different situations is mentioned as its aim. In this study we analyzed the qualitative and quantitative differences between the use of everyday and scientific conceptions in the pre-, the post-, and the follow up-test to rate the students' learning success.

Several studies have shown that students hardly reconstruct their conceptions, especially their everyday conceptions even after scientific-oriented interventions (Chinn & Brewer, 1993; Duit & Treagust, 1998; Treagust & Duit, 2008). A meta-analysis of different conceptual change-strategies has shown that explicitly contrasting students' everyday conceptions with the scientific ones can have positive effects (Guzetti & Glass, 1992). Metacognitive awareness of conceptions is also seen as beneficial for conceptual reconstruction and its sustainability because students reflect on their recent everyday conceptions and their learning process (Gunstone & Mitchell, 1997). Vosniadou (2002) differentiates between imaginatively generated conceptions and epistemological framing conceptions. Both are generated for abstract phenomena but epistemological conceptions, e.g. the *everyday realism* that was mentioned before, influence the whole basic understanding of a topic. They provide a framework for the other conceptions and can affect their understanding. Therefore, they are fundamental and even more difficult to reconstruct in learning processes.

The learning environments used in this study were designed according to these requirements.

3. Research questions

The study focuses on the following research questions:

- To what extent does instruction that explicitly considers individual students' conceptions, metaphors, and analogies support conceptual reconstruction?
- Which metaphors and analogies foster or hinder students' understanding of the process of seeing?
- How do different ways to gain understanding – by direct experience or imaginative mapping – influence the success and retention of conceptual reconstruction?

4. Research design and methods

To examine these research questions three different groups (*N* = 217, grades 8 and 9 (13 to 15 year old)) were compared in a pre-post-follow up-test-design. The intervention lasted two weeks and the treatment was different in all groups:

- Intervention group I: the students (n = 73) got material adapted to their individual conceptions, prominent metaphors, and analogies were explicitly reflected upon
- Intervention group II: the same material was used irrespective of students' (n = 71) individual conceptions, metaphors, and analogies
- Control group: the control group (n = 73) had no instruction concerning vision. In biology classes the control group was dealing with other topics like photosynthesis or the immune system.

To determine students' conceptions of seeing and perception, computer software was used (Dannemann & Krüger, 2010). The software measures the qualitative (Which conception is chosen in which situation?) and quantitative (How often is a conception used in different situations?) differences between the use of everyday and scientific conceptions to rate the students' learning success. To examine the second and the third research question, the conceptions of all students were tested before and after the treatment and in a follow up-test three months later to test the sustainability of the conceptual reconstructions. The control group B did not perform the follow up-test due to curricular demands. They learned about the topic of vision in the meantime. The results of the pre-, the post-, and the follow up-test were statistically compared using tests for non-parametrical data (Kruskal-Wallis, Wilcoxon).

Students' metaphors and analogies were analyzed using their drawings and comments on worksheets in the different learning environments. Qualitative content analysis (Gropengießer, 2005; Mayring, 2007) was used to interpret them.

4.1 Design of the learning environments

The process of designing the learning environments was based on the model of educational reconstruction (Kattmann, 2007). Everyday and scientific conceptions were compared and the results were used to design them. To figure out prominent and frequent everyday conceptions, studies about students' conceptions of the process of seeing were reanalyzed (e.g. Andersson & Kärrqvist, 1983; Gropengießer, 2001; Guesne, 1985; Wiesner, 1995). To complement the results a pilot study with five classes (N = 142) was conducted and prominent and frequent conceptions, metaphors and analogies were identified. The learning materials were designed according to the requirements of experimentalism and conceptual change mentioned above.

4.2 Prominent students' conceptions, metaphors, and analogies of seeing

The following sketches were drawn at the pretest of this study. They are used as examples to show prominent conceptions, metaphors and analogies. Similar sketches to draw on were used in several studies before (Andersson & Kärrqvist, 1983; Gropengießer, 2001). The students were asked to complete the sketch so that it explains their idea of the process of seeing.

Before the intervention student DR (initials of the students) drew arrows that point at the flower and also in the other direction (Figure 2). In the text below, he explains: "The eye emits seeing rays which are reflected back into the eye. That is how we see." This everyday conception is called *reflection*. DR uses a common metaphor, the start-path-goal schema twice in contrasting directions (Figure 2, green lines): first it is directed from the eye to the flower and represents a "seeing ray". These "seeing rays" "touch" or "hit" the flower and then are reflected back into the eye. To show that something is led to the brain DR uses the start-path-goal schema a third time.

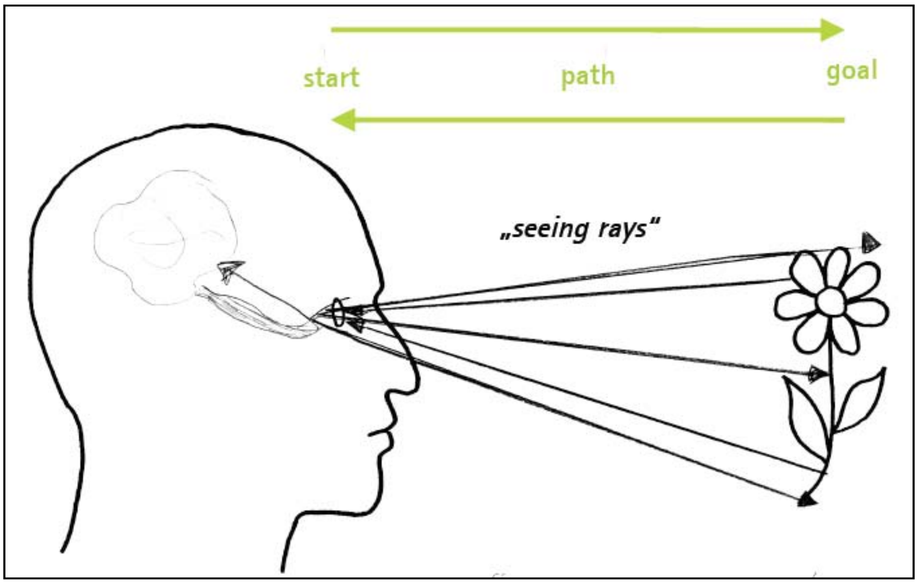

Figure 2. DR's drawing (black lines) before the intervention (pretest) as an example for students' conceptions of the *relation between object and eye.*

The second drawing (Figure 3) shows an *image* of the flower that is generated in the eye and turned around in the brain. In the pretest, 92 % of the students held the conception that an *image* of the original object is generated in the process of seeing. Most of them also think that this *image* is an exact copy of the object that is perceived and also have the epistemological conception of *everyday realism* as a conceptual framework. According to student RA the only function of the brain – that is not drawn but written down in the sketch of the head – is to turn the *image* around after it was reversed in the eye.

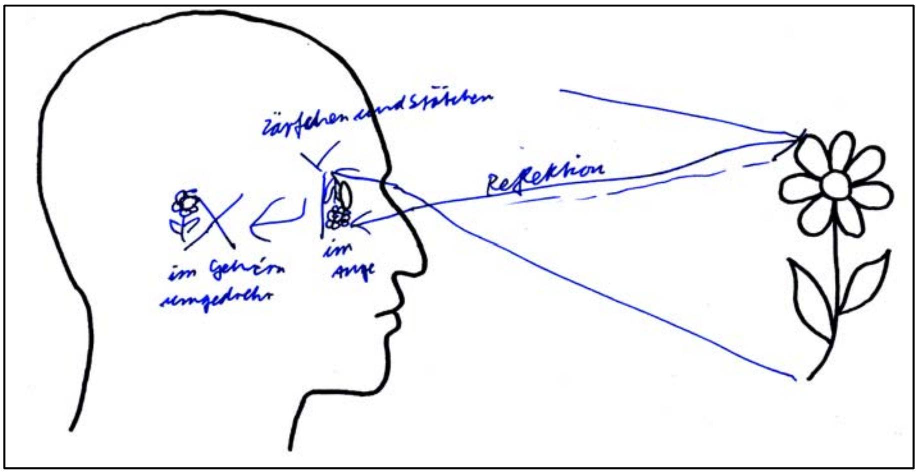

Figure 3. RA's drawing before the intervention (pretest) as an example for students' conception of an *image* that is generated in the process of seeing (text written down in the drawing from the right to the left side: reflection, cones and rod receptors, in the eye, turned around in the brain).

Figure 4 shows an example of a science-oriented conception. Student BC has additionally drawn light which was missing in the other examples. In the pretest, 63 % of the students do not have the reliable conception that light is necessary for seeing. To explain the *relations between object and eye* BC also uses the start-path-goal schema. And this metaphor is also helpful to describe the relations between the light source and the object. But in contrast to DR's drawing, the arrows in BC's drawing represent the light that is directed to the flower and is reflected into the eye. So he just draws the arrows in one direction. This gives clues that the conception of what is represented by the arrows is a key to a scientific understanding. BC has not drawn an *image* of the flower that is generated in the eye or the brain. In his opinion, information is sent to the brain.

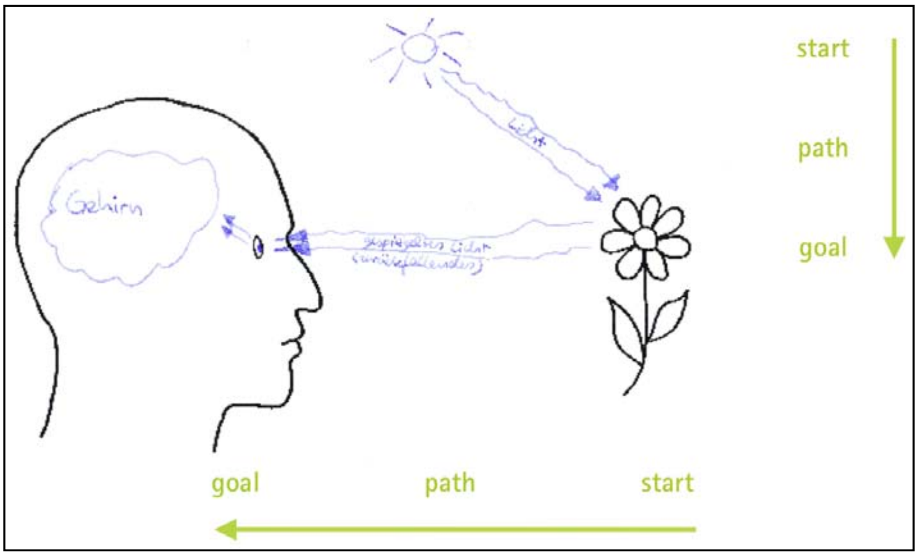

Figure 4. BC's drawing before the intervention (pretest) as an example for science-oriented conceptions of *light*, *relations between object and eye* and *image* (text written down in the drawing from the right to the left side: light, reflected and mirrored light, brain).

The results of the analysis of students' drawings and comments were used to design the learning environments for the intervention study.

4.3 Guidelines for the design of the learning environments

The theory of experientialism describes two different ways to gain understanding: providing direct experience and the reflection on conceptions. Some conceptions of seeing are experience-based, e.g. the *role of light*: To enable students to (re)construct their conception of this topic they are offered experiences with light. Therefore, we use a box with a back wall that is slowly opened while the student looks into the box. Consequently, he can experience that he sees nothing inside the box as long as there is no light. Based on this experience the student is given a possibility to reconstruct his conception concerning the *role of light*.

The interventions that deal with imaginative understanding are using prominent metaphors or analogies that are explicitly described and contrasted with the scientific conceptions. Students and scientific textbooks use the start-path-goal schema to explain what happens between the object and the eye in the process of seeing (cf. Figure 2 and Figure 4). Thus, the start-path-goal schema can be seen as a helpful metaphor to understand this part of the process of seeing. Student DR, for example, can retain his start-path-goal schema because even scientists use it to understand the scientific conception. But he has to invert the direction and to reconstruct his idea of the seeing rays that are emitted by the eye. Here the experience that light is necessary to see is helpful. It seems to be the missing link for explaining the processes between the object and the eye.

Understanding this process lacks direct experience. Therefore, we designed working sheets in a specific way: prominent metaphors of extrospection and reflection like "seeing rays", a "sonar", or "rays that measure out the object" are contrasted with the scientific concept that light is reflected from the object into the eye. The students can reflect on their individual conception. Sketches support this way of learning. They use the start-path-goal schema and contrast the representation of the everyday conception with the scientific one.

The learning environment for reconstructing the conception that an *image* is generated in the process of seeing reflects on a prominent analogy: the eye works like a camera and seeing is like taking a photo. Many students use this analogy because it is often described in physics or biology textbooks in order to foster students' understanding of the optical parts of the process of seeing.

To support metacognitive awareness and reflection the working sheets were structured in a specific way: at first the students have to phrase and/or draw their recent conception. Immediately after that they get in touch with the scientific conception which is explicitly contrasted with the everyday conception. Finally, they have to write down again their recent understanding and compare it with their statement before.

To answer the second research question the start-path-goal schema seems to be a very helpful metaphor to understand the processes between object and eye. In contrast, the analogies of the eye as a camera and an *image* that arises in the eye are hindering a scientific understanding. Therefore, we explicitly reflected on them in the learning environments.

5. Findings and discussion

5.1 The role of individual conceptions, metaphors and analogies in students' understanding of seeing

To examine whether the consideration of students' individual conceptions and metaphors helps to reconstruct their everyday conceptions, we tested their performance before and after the intervention. To analyze the sustainability of the treatment they were also tested three months later. The results of the three measurement dates were compared. The testing before the instruction showed no significant difference between the three groups (Kruskal-Wallis-test: pretest: .260 (n.s.)).

The results are presented for the three aspects: *role of light* (direct experience), *relations between object and eye* (imaginative understanding) and the *image* that is generated in the process of seeing (imaginative understanding in the epistemological framework of *everyday realism*). Therefore, the results also give clues to respond to the third research question.

5.2 The *role of light* – Direct experience

Concerning the *role of light* significant differences could be shown in both intervention groups from pre- to posttest.

Table 1. The *role of light* – Comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .001$ $r = .61$	$p < .001$ $r = .44$	p = n.s. $r = .21$
Intervention group II	$p < .001$ $r = .43$	$p < .05$ $r = .28$	p = n.s. $r = .11$
Control group	p = n.s. $r = .05$		

The effect in intervention group I is even larger than in intervention group II – more students have reconstructed their conceptions (intervention group I: 44%; intervention group II: 21%). The results of the follow up-test show that the students of the intervention group I retained the scientific conception better. Between the post- and the follow up-test no significant differences were found. As expected, no significant differences were also found in the control group between the pre- and the post-test. So if direct experience is possible students profit even if their individual conceptions are not explicitly mentioned. But if individual conceptions are considered more students are reconstructing them and retain them longer.

5.3 The *relations between object and eye* – Imaginative understanding by using the start-path-goal schema

The results show that only students from intervention group I reconstructed their everyday conceptions. They were even able to use the scientific conception in the follow up-test.

Table 2. The *relations between object and eye* – Comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .001$ $r = .41$	$p < .05$ $r = .32$	p = n.s. $r = .17$
Intervention group II	p = n.s. $r = .11$	p = n.s. $r = .06$	p = n.s. $r = .05$
Control group	p = n.s. $r = .04$		

Comparing these results with the reconstruction of the light-conception the effect sizes are smaller. Imaginative understanding seems to be more difficult to reconstruct. Therefore, only if the individual conceptions are considered and the metaphors concerning the *relations between object and eye* are explicitly reflected students will be able to reconstruct their everyday conceptions.

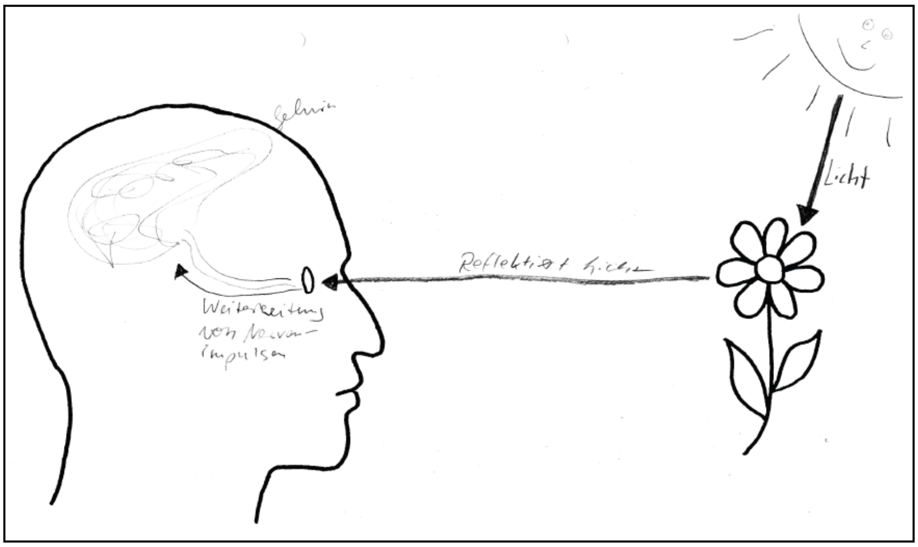

Figure 5. DR's drawing after the intervention (posttest), (text written down in the drawing from the right to the left side: light, reflects light, transmission of nerve impulses, brain).

The qualitative analysis of the students' comments on the learning material also shows this necessity of an explicit reflection of metaphors. DR has reconstructed his conception of "seeing rays" in the post- and in the follow up-test. He uses a science-oriented depiction: light shines on the flower and light is reflected from the flower into the eye (cf. Figure 5).

Another student (KJ) reflects his learning process as follows: "The ideas I mentioned before are not right, because the reflected light is falling into my eye and is not coming from the eye. There are no rays that enable us to see, there is only light that is directed into the eye." This exemplifies that students are able to reconstruct their conceptions using a start-path-goal-schema. This schema can be seen as a very helpful metaphor to understand what happens between the object and the eye in the process of seeing. But it has to be combined with the right "content", i.e. that the students need a conception of what is "moving" from the object into the eye. Therefore, the conception of the necessity of light should be reconstructed first.

5.4 An *image* is generated in the process of seeing – Imaginative understanding by using the *image*-analogy

This conception is the second example for imaginative understanding. The very common analogy "The eye is like a camera" which is often used at school is reflected in the learning material. Students that hold the epistemological conception of *everyday realism* often describe this conception.

Table 3. An *image* is generated– comparison of the results of the pre- and posttest, and the follow up-test (Wilcoxon)

	Pre-Post-Test	Pre-Follow up-Test	Post-Follow up-Test
Intervention group I	$p < .01$ $r = .33$	p = n.s. $r = .24$	p = n.s. $r = .28$
Intervention group II	p = n.s. $r = .17$	p = n.s. $r = .08$	p = n.s. $r = .16$
Control group	p = n.s. $r = .01$		

Looking at the statistical data it becomes obvious that just a few students of the intervention group reconstructed their conception of an *image*. The effect size is very small and the effect is lost in the follow up-test. This shows the difficulty to reconstruct the conception of an *image*.

What are possible causes for this difference? Firstly, the analogy of an *image* that is generated in the eye is often reconfirmed in biology and physics lessons in school: the camera is used as a model of the eye and the photo as a model of the experience we have while we are seeing. A problem is that the limitations and difficulties of this analogy are not reflected in most cases. More basic is that our experience itself seems to be analogue to a picture of our environment we have in mind. This also matches to the epistemological everyday conception of *everyday realism*: we see the world as it is. So 92 % of all students use metaphors of *images* to explain the process of seeing. They seem to be fundamental for our everyday understanding because of our self-experiences.

In this case, learning environments have to implement a conflict between the fundamental epistemological framework and our self-experience of seeing. Thus, the learning material was designed to offer a metacognitive critique of the *image*-analogy and explain the scientific conception. However, it was not offering an alternative analogy.

Some students successfully reconstructed their conception of an *image* even in the follow up-test. Qualitative analyses of their drawings and comments on the worksheets show what makes their reconstruction partly successful. Figure 6 shows RA's drawing from the posttest. RA did not reconstruct her conception of an *image* in the scientific way: she has not constructed the scientific conception that we cannot perceive the image on the retina. For her the *image* conception is still helpful but she is aware that this representation is just a model. She comments on her drawing: "There is no image but just electronic streams." Even in the follow up-test she is not drawing an *image*.

Other students formulated their metaconceptual awareness in phrases like "virtual image", "digital image" or "just a comparison or a model" after the instruction instead of "real image" that was often used before. Students do not find an alternative analogy that is plausible or fruitful for them to replace or reconstruct the *image* metaphor. But students are able to reconstruct their conception of an *image* if they can classify it as an analogy.

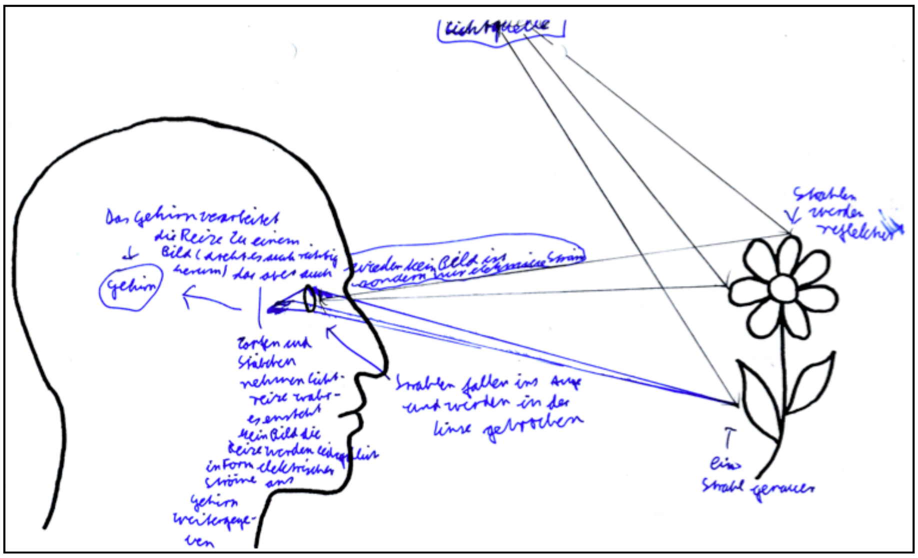

Figure 6. RA's drawing after the intervention (posttest), (parts of the text written down in the drawing from the right to the left side: rays are reflected, rays are reflected in the eye and are refracted in the lens, an *image* is not created but electronic currents are transmitted to the brain).

The described examples indicate that a key to scientific understanding is if individual conceptions, metaphors, and analogies are explicitly mentioned and reflected upon. In most cases students' results were significantly better if their individual conceptions were considered. Notably, abstract conceptions may only be reconstructed if the individual conceptions, metaphors, and analogies are mentioned.

5.5 Differences between different ways to gain understanding

In relation to the third research question, the data shown above shows differences between the different ways to gain understanding. If conceptions are experience-based, students can reconstruct them independently from the consideration of their individual conceptions. However, more students will reconstruct their conceptions if their individual conception is considered or reflected upon.

Conceptions of abstract phenomena that are based on imaginative understanding are only reconstructed if the individual conceptions and metaphors are reflected upon explicitly. The metaphor of start-path-goal can be seen as very helpful for a sustainable conceptual reconstruction.

Metacognitive awareness seems to be necessary to reconstruct very fundamental metaphors and analogies. The analogy of the *image* is correlated with the conception of *everyday realism* as an epistemological framing conception. That makes it very difficult to reconstruct. To enable students to reconstruct this conception it is necessary to strengthen phases of reflection in the learning material. Limitations and problems of this analogy have to be accentuated. This has to be taken into account to design a revised version of the learning material that will be tested in a following study.

6. Summary

In most cases the results of the students were significantly better if their individual conceptions were considered and reflected upon. Notably, in this study abstract conceptions were only reconstructed if the individual conceptions were explicitly mentioned.

The interpretation of students' metaphors and analogies shows that they can be the key to successful reconstruction of abstract conceptions under the condition that they are reflected upon explicitly. The metaphor of start-path-goal is a very helpful metaphor to understand the process of seeing. In contrast, the analogy of an *image* hinders scientific understanding.

Different ways to gain understanding influence the success of conceptual reconstruction: if direct experience is possible, students reconstruct their conceptions even if they are not explicitly reflecting on their individual conceptions. If imaginative understanding by metaphors or analogies is necessary, students in this study were only able to reconstruct their abstract conceptions if they were explicitly reflected upon.

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