Norwegian pupils' understanding of reproduction and inheritance in the 4th grade

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Abstract

Two open-ended and two multiple choice items from TIMSS 2006 field test and 2003 main survey are analysed. All items are in biology, concerning aspects of reproduction and inheritance. The open-ended questions are classified in detail in order to investigate pupils' understanding and to reveal preconceptions. The answers varied a lot, from being in accordance with school science to seemingly without any scientific reasoning. Many of the "wrong" answers revealed interesting understanding of the topic in question, although with plain and inaccurate attempts of explanations. Such answers might be useful in classroom situations, if the teacher is able to sort out the relationships with the biological theory.

Introduction

Everything in biology might be simplified to aspects of survival and reproduction. Being fundamental for life, however, does not imply equal importance in school science.

Reproduction is part of the Norwegian curriculum from the 3rd grade, as a simplified version of the human life cycle is introduced along with a few other life cycles (KUF, 1996). More details concerning reproduction are not given until the 5th and 6th grade. Thus, pupils' answers on reproduction and inheritance in the 4th grade might probably reveal their prior / daily-life understanding.

Many authors point out the formidable literature showing that pupils develop ideas about nature prior to school instruction (e.g., Palmer, 1999; Morrison & Lederman, 2003). The underlying concern in this kind of research is the achievement of a better understanding of how pupils acquire new knowledge, and thus how to teach them in the best way (e.g., Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Pupils are interpreting what they learn in school in terms of their existing ideas, which in turn might be modified in light of the newly acquired knowledge. This "constructivist view" is the dominant paradigm of learning in science (e.g., Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Pupils' strategy of interpreting the unknown in terms of the known might be exemplified by giving human characteristics to other organisms, like suggesting cultural practices as scientific explanations.

Whether the daily-life understanding agrees with the scientific worldview is highly variable (e.g., Helm & Novak, 1983; Novak, 1987). Surveys of pupils' conceptions and misconceptions are therefore important. The research on pupils' preconceptions often shows that these differ a lot from the accepted scientific viewpoints (Palmer, 1999). Many surveys of pupils' conceptions have been performed on topics in physics (e.g., Angell, 2004; Liu & McKeough, 2005). Studies on topics in biology have also been conducted, although much less than in physics (Bishop & Anderson, 1990; Hagman, Olander, & Wallin, 2001; Sinatra, Southerland, McConaughy, & Demastes, 2003; Dagher & Boujaoude, 2005; and see Tanner & Allen, 2005). A comprehensive database of studies in students' and teachers' conceptions related to science education is compiled by Duit (2006).

The identification of these "misconceptions" or "alternative conceptions" gets especially important as pupils learn by linking new information to their existing worldview. Thus science teachers should be able to identify pupils' scientifically acceptable conceptions as well as their alternative or scientifically wrong conceptions (e.g., Palmer, 1999; Morrison & Lederman, 2003; Tanner & Allen, 2005).

To which degree do the pupils' preconceptions form a base for learning science or mere obstacles? Some authors point out a large gap between everyday thinking and the scientific viewpoints (e.g., Aikenhead, 1996; Cobern, 1996). Others regard the every-day sense-making of pupils as a useful base for learning (e.g., Clement, 1989). In this tradition, the relationship between pupils' and scientists' worldviews is assumed to be complex; ranging from similarity to difference, to be complementary or just generalizations (e.g., Warren et al., 2001). Authors in this tradition regard some of the pupils' preconceptions from daily life as useful "starting points" for understanding scientific topics or theories (e.g., Brown, 1997).

The present study investigates pupils' answers on questions concerning reproduction and inheritance in the 4th grade, and classifies the answers according to correspondence with the scientific worldview. The answers are not only categorised based on being "right" or "wrong", but the "wrong" answers are further separated based on presence of relationships with biological scientific theories. Common answers that seem to have no relation to science are also given categories. Whether or not the pupils' ideas will serve as a base for further learning is discussed, together with possible causes for widespread non-scientific beliefs.

Thoroughly, I have tried to transfer the misspellings in pupils' answers from Norwegian to English.

Materials

TIMSS (Trends in Mathematics and Science Study) contains a considerable amount of open-ended and multiple choice questions. A few thousands of pupils are involved in this test in Norway, and all answers are collected and categorised. This represents a unique data set of pupils' achievements and understanding in science and mathematics.

Two open-ended biology items given in the field test in TIMSS 2006 are analysed in detail in the present study. These items concern aspects of reproductive biology in the 4th grade, and they are not included in the TIMSS 2007 main study. Additionally, two multiple choice items from TIMSS 2003 concerning inheritance are analysed.

Selected items with classifications and results

Reproductive biology

Rats and mice

Item no. S041170, 2006 field test (deleted from the main test in 2007):

Can a rat and a mouse mate and produce offspring?

(Check one box.)

Yes

No

Explain your answer.

To get fully correct in the field test scoring guide, pupils should check "No" and explain that the rat and mouse are different species, different types of rodents or different kinds of animals. Answers like "Yes, they are in the same family" are classified as wrong.

In the present study, a far more detailed categorisation is accomplished in order to investigate the pupils' knowledge and understanding of hybridisation and mating between closely related taxa.

Altogether 225 pupils answered the booklet containing this question. Two answers were blank, and 63 had only some kind of stray marks. In addition, 26 answers were not classified (these includes misunderstandings of the question and answers like “because a plant can’t move” or “No, they are not alive”.) The remaining 134 answers were classified according to the criteria given in Table 1. The percentages of answers within each category are given in Table 2, calculated from the total amount of participating pupils, including the blank answers.

The classification used might be discussed, as answers in category F are not necessary caused by thinking from a human viewpoint. Likewise, answers in category G might be the result of some biological reasoning, as pupils are thinking on morphology. However, the categories are treated separately in the discussion.

Table 1. Classification of answers to item no. S041170: Can a rat and a mouse mate and produce offspring?

	Kind of explanation
	Biological explanations
A	No. Refers to different species, types or kinds of animals. (“No, because it is not the same species.”)
B	Yes. Refers to close relationship between the animals. (“Yes, because they are in the same animal family” or “Yes, because they are almost totally the same animal.”)
C	No. Refers to unsuccessful hybrid offspring. (“No, then it could be too strange offspring.”)
D	No. Refers to habitat differences. (“No, because the rat lives in the sewer.”)
	Human viewpoint
E	Yes. Refers to marriage or dating prior to making offspring. (“Yes, because they can marry.”)
F	Yes. Refers to rats being males and mice being females. (“Yes, because mouse is a woman and the rat is man.”)
	Other common explanations
G	No. Refers to rats being larger than mice. (“No, because the rat is larger.”)
H	No. Refers to rats eating mice. (“No, I think the rat can eatt the mouse.”)

Table 2. Numbers and percentages of answers in each of the categories given in Table 1. The percentage is calculated from the total amount of participating pupils, including the blank answers. Explanations of the categories are given in Table 1.

	Number of answers	Percentage
A	62	28 %
B	34	15 %
C	8	4 %
D	1	0.4 %
E	3	1 %
F	7	3 %
G	18	8 %
H	4	2 %

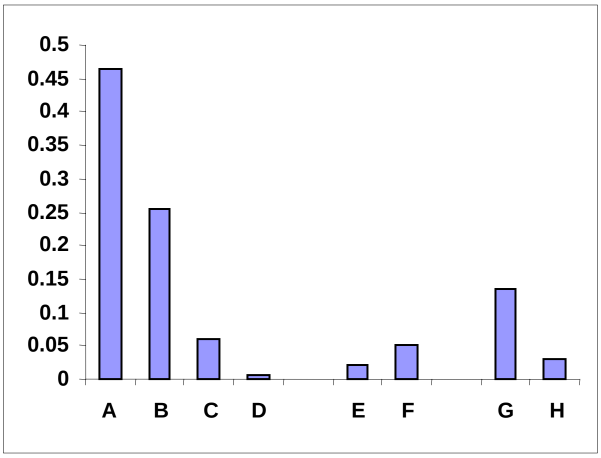

Figure 1. Proportions of answers in each category for item no. S041170, calculated from the number of classified answers. Explanations of the categories are given in Table 1.

Altogether 28 % of the pupils gave answers in category A (Tables 1 and 2, Figure 1), choosing “no” and referring to different species or kinds of animals. Another common kind of answer was “yes” with reference to rats and mice being closely related, chosen by 15 % of the pupils. Some pupils (4 %, category C), chose “no” and explained that the hybrid offspring would be too strange or does not exist in nature. Only one pupil gave an answer related to habitat differences (category D).

Some pupils chose “yes” and explained that dating or marriage was the necessary action prior to producing offspring (1 %, category E). Altogether 3 % of the pupils believed that rats are men and mice are females (category F). A rather common kind of answers was “no” with reference to rats being larger than mice (8 %, category G); while 2 % of the pupils believed that rats eat mice and answered “no” (category H).

Animals in plant reproduction

Item no. S041021, 2006 field test (deleted from the main test in 2007):

Name an animal that plays a part in plant reproduction.

Describe what the animal does.

To get fully correct in the field test scoring guide, pupils should name an animal and describe what the animal does to aid pollination or dispersal.

In the present study, another categorisation is accomplished in order to investigate the pupils' knowledge and understanding of animals that contribute to plant reproduction, including the wrong answers.

Altogether 188 pupils answered the booklet containing this question. Of these, 69 answers were blank, and two had only some kind of stray marks. Thus only 117 pupils have answered the question. In addition, 36 answers were not classified (these includes misunderstandings of the question and answers like "A large animal brown with horns" or "Ant. Have no idea".) The remaining 81 answers were classified according to the criteria given in Table 3. The percentages of answers within each category are given in Table 4, calculated from the total amount of participating pupils, including the blank answers.

Table 3. Classification of answers to item no. S041021: Name an animal that plays a part in plant reproduction. Describe what the animal does.

	Kind of explanation
A	Refers to pollination or taking nectar. ("The bees. When they shall suck nectar from a flower they get pollen on themselves which fall off a little by little.")
B	Refers to animals making the soil better for growth or making manure. ("Horse. It eats a lot of strange things like dry plants etc. Then it shits. It can be used as good manure.")
C	Refers to animals (especially earthworms) digging tunnels for the plant roots or water trickling through the ground. ("Earthworm. It makes holes where wate can sep through." or "Digs tunnels.")
D	Refers to animals eating plants. ("The snail can eat the flower.")
E	Refers to animals doing something else with flowers, like camouflaging themselves or dancing around the plants. ("Tiger. It plays with the flower. It runs around the flower.")

Table 4. Numbers and percentages of answers in each of the categories given in Table 3. The percentage is calculated from the total amount of participating pupils, including the blank answers. Explanations of the categories are given in Table 3.

	Number of answers	Percentage
A	30	16 %
B	11	6 %
C	6	3 %
D	15	8 %
E	19	10 %

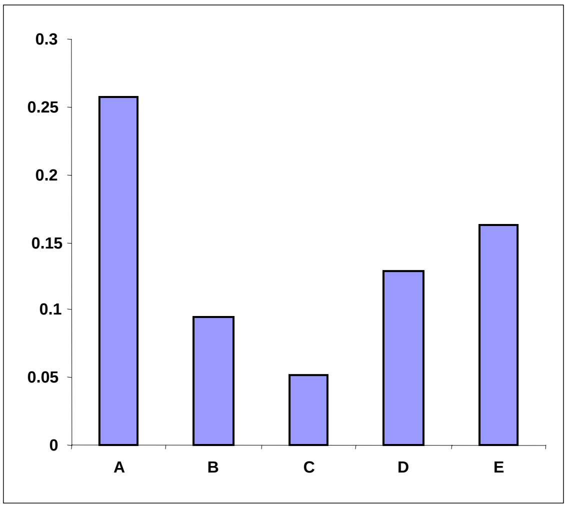

Figure 2. Proportions of answers in each category for item no. S041021, calculated from the number of classified answers. Explanations of the categories are given in Table 3.

Altogether 16 % of the pupils gave answers related to pollination (category A in Tables 3 and 4, Figure 2). Answers relating to soil or manure were rather common (6 %, category B), while 3 % of the pupils answered earthworm and explained that they are digging tunnels in the ground for plant roots or water (category C). Altogether 8 % of the pupils mentioned animals eating plants (category D; they were not mentioning seeds, and not referring to dispersal). Some pupils, 10 %, mentioned animals doing something else with plants like camouflaging themselves (category E).

Inheritance

Yellow flowers
Item no. S031269, 2003 main survey (released):
A plant has yellow flowers. What best explains why the flowers are yellow?
A The sunshine colored the flowers yellow.
B The flowers of the parent plants were yellow.
C It was very warm when they flowered.
D It rained every day.

The correct answer is B; the flowers of the parent plants were yellow. Altogether 677 Norwegian pupils answered. Of these, 23.1 % chose A, 55.9 % chose B, 14.0 % C and 4.0 % D. The international average frequencies were 18.5 % A, 53.5 % B, 18.4 % C and 6.2 % D.

Adult height
Item no. S031269, 2003 main survey (released):
What will most likely affect your adult height?
A The height of your parents
B The height of your brothers and sisters
C Your hair color
D Your weight

The correct answer is A; the height of your parents. Altogether 711 Norwegian pupils answered. Of these, 62.0 % chose A, 5.2 % chose B, 1.2 % C and 29.3 % D. The international average frequencies were 42.1 % A, 8.0 % B, 4.9 % C and 42.4 % D.

Discussion

Rats and mice
Pupils were asked whether a rat and a mouse can mate and produce offspring. In most cases, different species can’t breed and make successful and fertile offspring, unless the result is a new species (hybridization). This is actually the definition of being a species, according to the biological species concept. Altogether 28 % of the Norwegian pupils’ answers correspond with this (category A in Tables 1 and 2, Figure 1). The percentages are calculated from the total amount of participating pupils, including blank answers.

Interestingly, 15 % of the pupils answer that rats and mice can make offspring, and refers to the close relationship between these animals (category B in Tables 1 and 2). These pupils certainly have knowledge about the species in question, and refer to them as mammals or being part of the same family. Although the theory (the biological species concept) set the limit for being able to produce fertile offspring at the species level, there are not so definite limits in nature. In general, the chance of hybridization increases as the parent species are more closely related.

Furthermore, the “successful and fertile offspring” in the biological species concept is not the same as “offspring” solely. There are well known examples of crosses between different species resulting in offspring, like the sterile mule (parents are horse and donkey). Some pupils (4 %, category C in Tables 1 and 2) refer to the possible offspring being “too strange” or that such intermediates between rats and mice do not exist in nature. One pupil describes a possible offspring as “being as little as a mouse with a tail like a rat”.

A problem with the biological species is that the limits between species have to be tested experimentally. We don’t know from the present distribution of species whether they are able to reproduce with each other or not, e.g., geographically isolated groups might belong to the same species although looking somewhat different. There is a theoretical possibility that some species of rats and mice might produce fertile offspring, if brought together. Habitat differences also contribute to species isolation, and there is one pupil that refers to this (“no, because the rat lives in the sewer”, category D in Tables 1 and 2).

Furthermore, there are loads of organisms that definitely do not fit into the biological species concept. A striking example is asexual organisms. Biologists have different species concepts, which are more or less suitable for the various species groups. Sometimes the limit between two species is clear-cut in one part of the world and blurry elsewhere. There might be gradual differences within a species along a geographical gradient, whereas the individuals in the endpoints belong to different species according to the biological species concept. A well-known example is two species of gulls in Northern Europe, which is related through a gradient of intermediates crossing Siberia, Alaska and Northern Canada.

In the scientific language, it is more specific to belong to the same genus than to the same family. In Norwegian, the word for family (“familie”) means a more close relationship than the word for genus (“slekt”) in non-scientific connections. This might confuse Norwegian pupils.

Some pupils interpret the animals based on human behaviour. Approximately 1 % of the pupils answer that the rat and mouse can have children, if they first marry (category E in Tables 1 and 2). In Norwegian the verb “can” also have the connotation “be allowed to”. Some pupils might invoke moral or religious justifications, thus mentioning marriage before having children. Another example of interpretation from a human viewpoint is “Yes. They can met each otther They can eat together and become sweethearts and mate”.

Another common type of answer is exemplified by “Yes. A rat is a man and a mouse is a lady and hav they children together.” Altogether 3 % of the pupils answered variants of this (category F in Tables 1 and 2). The underlying reason seems unclear. Do the pupils associate rats with men and mice with women based on what they look like, masculine-looking rats and feminine-looking mice? Mice are usually perceived as cute, while sewer-living rats do not have similar positive associations. Is the idea caused by the size differences of the animals? Answers relating to size differences were frequent (8 % of the pupils, category G in Tables 1 and 2).

The last category of answers suggests that rats eat mice (2 %, category H in Tables 1 and 2). People stay away from wild rats living in the sewer, and are afraid rats might bite or spread diseases. Mice can as well spread diseases, but this is not so well-known. Rats are also known as being able to eat “everything”. Thus it is not surprising that pupils think that rats are dangerous for mice.

Animals in plant reproduction

Pupils were asked to identify an animal that take part in plant reproduction, and describe what the animal does. There are two processes in plant reproduction where animals can contribute, pollination and dispersal. Few Norwegian pupils gave answers that might be related to dispersal, and these are not classified in the present study. The few answers with some relevance are “Horse. It eats flowers and defecate it out another place” and “The shiraf (giraffe). The animals shake it then it will reproduce”. I am doubtful whether these pupils actually are thinking of dispersal.

Pollination, on the other hand, seems to be more well-known among the pupils. Pollination might also be the first thing these pupils associates with animals contributing to plant reproduction, i.e., they might have answered dispersal as well if asked for two kinds of interactions. Altogether 16 % of the answers relates to pollen, nectar or honey; naming bees, wasps or bumblebees as the transfer agents (category A in Tables 3 and 4, Figure 2). These answers might be simple (“Bumblebee. Carries honey”) or somewhat more elaborate (“The bumblebee takes pollon from flower to flower” or “The bees. When they shall suck nectar from a flower they get pollen on themselves which fall off a little by little.”) Other pollination agents, for example flies, are totally absent in the material. A few pupils mention butterflies, but as they are not giving any explanation their answers are not included in this category.

Some students seem to mix up reproduction with growth. They refer to animals making the soil better for growth or making manure (6 %, category B in Tables 3 and 4). Examples are “Horse. Theirs dung is used as manur” and “The hen. It makes manure”. This is related to the next category of answers, where 3 % of the pupils tell that earthworms contribute to improve reproduction by digging tunnels helping the plant to grow (category C in Tables 3 and 4). A few more examples are “Animales makes breathing holes in the earth (earthworms)” and “Earthworm. The earthworm digs down in the earth and cleans it”.

Plant reproduction is not always mediated through seeds. Being modular organisms, vegetative propagation through stolons or rhizomes is an important mode of reproduction in many, many plant species. Thus plant growth might contribute directly to reproduction – when a plant is split in two, you might get two functional individuals. This is how many plants in the garden and potted plants reproduces, for example garden strawberries, and pupils might have seen this at home. As the border between plant growth and reproduction is unclear in real life, no one should wonder why it is unclear for a pupil.

Furthermore, “growth and reproduction” is a common set phrase, e.g., “contribute to growth and reproduction”. In the Norwegian translation, the word used for reproduction (“formering”) is not commonly used among 9 year olds. This clearly makes it more difficult for the pupils to figure out what they should answer. However, the other word that might have been used is even more unfamiliar (“reproduksjon” which is a direct translation of reproduction).

Another common kind of answer was variants of animals eating plants, like “Frog. It takes the tongue out and eats it” and “Roe deer. It eats bark on the treens. And eats tulips” (8 %, category D in Tables 3 and 4). At least these pupils refer to a plant-animal interaction, although not contributing to reproduction (eating seeds and dispersal is not mentioned).

The last category contains rather different kinds of animal actions, which have nothing to do with reproduction, growth or eating (10 %, category E in Tables 3 and 4). Examples are “Bumblebee. They smear something on the berries so they will get large”, “Earthworm. It keeps insect away from the flower” or “Cat. The cat likes to go out in nice weather and pass along flowers and likes to play”. Some pupils mention hedgehogs, tigers and elephants, which seems more like guessing than any reasoning. They might just select animals they find fascinating.

Inheritance
Two multiple choice items relating to heritage were given. One of them asks for the best explanation of why flowers are yellow, where the pupils should choose “the flowers of the parent plants were yellow” to get correct. Altogether 55.9 % of the Norwegian pupils answered this, close to the international average of 53.5 %. The alternative “the sunshine colored the flowers yellow” was also popular, and chosen by 23.1 % of the Norwegian pupils (the international average was 18.5 %). Surely the yellow colour is partly caused by the sunshine (light), with the yellow coloured wavelengths being reflected. The other two alternatives were not very frequent (“it was very warm when they flowered” chosen by 14.0 % and “it rained every day” by 4.0 %, international averages 18.4 % and 6.2 % respectively).

The other multiple choice item asks the pupils to choose among variables that affects adult height. The most frequent alternative was the correct one, “the height of your parents” chosen by 62.0 % of the Norwegian pupils. The international average was 42.1 %. Two alternatives were seldom checked, both by the Norwegian pupils and on average internationally (“the height of your brothers and sisters” and “your hair color”). On the other hand, the alternative “your weight” was chosen by many pupils (29.3 % in Norway and 42.4 % internationally). While weight on average surely is correlated with height, it seems like a misunderstanding to choose that weight affects height.

Concluding remarks

The analysed open-ended questions both had some scientifically ambiguities, and were excluded from the main survey. However, these ambiguities might have contributed positively to the richly variable answers.

What can be learnt from such a collection of pupils’ answers? As mentioned in the introduction, two traditions are identified in the research on pupils’ preconceptions (e.g., Warren et al., 2001). Should pupils’ misunderstandings be erased and replaced by correct theory, or rather used as a resource in the learning of science? The detailed analyses of selected items in the present study reveal a span in the “wrong” answers, from scientifically meaningful reasoning to misunderstandings. Clearly, a teacher could use many of these answers in classroom situations. An understanding of pupils’ wrong answers is in general regarded as a useful resource in science instruction (Tanner & Allen, 2005).

In the “rat and mouse”-question the answer categories A – D could be a doorstep to much more interesting and fascinating biology than only category A, which is strictly linked to the definition of species in the biological species concept. In the “animals in plant reproduction”-question categories B and C could be similarly used. Of course, many answers are seemingly without any connection to science and scientific thinking. Whether pupils’ answers are fruitful for classroom discussions differs, but answers that seem to be wrong compared to the key might contain scientifically correct ideas.

As mentioned in the introduction, this requires that the science teacher is able to recognize the meaningful parts of the pupils’ often plain and inaccurate attempts of explanations (e.g., Palmer, 1999; Morrison & Lederman, 2003). This requires that the teacher knows and has a deeper understanding than merely the contents of the curriculum at the given level. In Norwegian schools, however, teachers at grade 4 usually lack any specific education in science after obligatory schooling (Grønmo, Bergem, Kjærnsli, Lie, & Turmo, 2004).

A teacher with poor knowledge of science might be more tied up to the textbook, curriculum and key; or might confuse scientific theories themselves. Telling pupils that their ideas are useful will be more motivating than telling them that they are wrong. This is, however, not equal to telling them that all their ideas are scientifically meaningful. Although some “wrong answers” might be useful in the development of refined scientific understanding, other preconceptions would rather impede the comprehension of science and should be replaced (Brown, 1997).

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