Do boys and girls understand physics differently?

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Boys and girls differ significantly in physics instruction: boys achieve higher grades in tests and are more interested in learning physics than girls [1, 2]. With regard to social and linguistic behaviour, we claim that boys and girls hold different notions of what it means to understand physics. Briefly, girls seem to think that they understand a concept only if they can put it into a broader world view. Boys appear to view physics as valuable in itself and are pleased if there is internal coherence within the physics concepts learned.

Research on gender differences has clearly shown that boys and girls differ substantially with regard to making sense of physics as presented in what may be called traditional physics classrooms [3]. There are also studies indicating that girls' interests in learning physics, and as a result also their learning outcomes, may be significantly improved by embedding the content to be learned in appropriate contexts. In this respect powerful contexts are ones that show the relevance of the particular content to daily life or are concerned with the public discussion of the risks and advantages of certain modern technologies, understanding features of the human body, and also phenomena that touch emotions and feelings [4]. The good news is that contexts that are meaningful for girls are usually also meaningful for boys, though the reverse does not hold. The above research findings are well known among educational researchers but appear to be less familiar to the physics education community.

There are also significant differences between boys and girls with regard to their social behaviour, their working methods and their use of language [5]. In this paper we focus on these differences. We briefly summarize the findings of an exploratory study on students' social and verbal interactions in whole class situations and in group work. The findings are preliminary and have to be investigated further in subsequent studies. However, it appears that the hypothesis that boys and girls hold different notions of understanding physics provides a consistent framework to explain differences concerning interests as well as social and verbal behaviour. We aim to develop conclusions in order to improve physics learning for boys *and* girls.

The study

An instructional unit on limited predictability of chaotic systems was taught to some 25 students aged 16+ (about the same number of boys and girls) in a Viennese Grammar school (for details of the unit see [6, 7]). The first author taught these students. The chaotic pendulum shown here in figure 1 played a key role. An iron bob swings over three symmetrically arranged magnets which are randomly distributed. When the bob is released several times from (as near as possible) the same spot, the resulting path is different every time. The limited predictability of this pendulum is due to certain zones of unstable equilibrium between the three magnets. Small differences in the starting

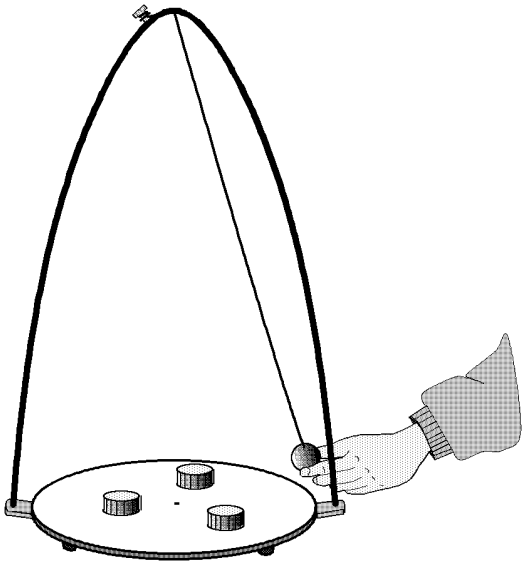

Figure 1. The pendulum investigated by the students.

conditions and small disturbances while the bob is swinging result in totally different paths after passing these zones a couple of times.

The lessons consisted of five sessions of 45 minutes each. Group work arranged as quasi open inquiry sessions dominated. Whole class activities served to introduce the group work and to summarize findings. Students first investigated whether the distribution of target magnets actually is random, explored the forces acting on the pendulum bob and then tried to explain the surprising behaviour. Then they studied a computer simulation of the chaotic behaviour and finally designed their own chaotic systems. Whole class activities and group work were documented with a video camera and afterwards transcribed. Interactions between students and the teacher in whole class periods and interactions among students within groups consisting of boys and girls are interpreted as follows.

How boys and girls respond to the teacher's questions

It is a well known general finding of research on gender differences in science classes that boys dominate the conversation between the teacher and the students [8]. This was also true in our lessons. A prudent inspection reveals further interesting differences between boys and girls.

First, closed questions posed by the teacher are more frequently answered by the boys; open questions resulted in stronger participation by the girls. Closed questions are part of a thematic pattern given by the teacher; the teacher expects one possible answer. If the teacher hears several answers, he or she selects the one that fits for approval and repetition. Open questions are more similar to real questions that are used in daily life: there are many ways of answering these questions and the outcome has to be discussed. An example of this might be when the teacher asks 'Why do you think the pendulum is moving like that?' or s/he might start in the following way: 'The movements of the pendulum are the results of forces acting on the pendulum. Which forces are acting on the pendulum?' (See also [9].)

Secondly, boys tend to answer more frequently than girls in a clipped telegram style using only half sentences or merely nominal phrases. They also start to speak in technical physics terms very early on. The girls, in contrast, more often than the boys, answer in complete sentences without employing technical terms but drawing on vocabulary from everyday language.

These differences in answering questions seem to have important consequences. Understanding the girls' ideas takes more of the teacher's time and effort. It also tends to nail them down to a particular message. In contrast, boys' preference for the telegram style answers allows a broader range of interpretation for the teacher. Their use of technical terms appears to indicate that the boys have something in mind that is correct from the physics point of view. In combination with their self-assured, dominating, behaviour this results in teachers taking the boys' answers more seriously. Consequently, girls' limited self-confidence in physics, which is reported in many studies [10], is further established.

The following example illustrates the different behaviour of boys and girls in answering the teacher's questions in our lessons.

The teacher begins the lesson with a demonstration of the behaviour of the chaotic pendulum. Students are asked for predictions of what will happen. Then she asks the students to predict what will happen if the pendulum bob is started from the same position for a second time. There

are nearly equal numbers of girls and boys in the class and usually the girls of this class have better marks than the boys in all subjects. Nevertheless it is only the boys who spontaneously offer their opinions. Only two girls begin to speak, one of them is Julia:

Teacher: Different magnet. Chance. Are their other opinions? What would the movement of the pendulum look like?

Julia: Similar.

Teacher: What do you mean by that?

Julia: Yes, it will be also a zig-zag motion.

Teacher: A zig-zag motion.

Boy: There are too many parameters which have to be taken into account.

The boy's remark stops the discussion between Julia and the teacher. It is only in the following group work session that a new opportunity for the girls to discuss the pendulum arises. Girls and boys work separately, discuss open-ended questions and write down their results. Every group has to prepare a final statement. When discussing these statements with the whole class the girls are now more involved than the boys.

Boys' and girls' different roles and behaviour in group work

Research has shown that boys and girls tend to take certain roles in mixed gender groups when carrying out experiments. The boys dominate, they run the show, so to speak. Girls often take the role of writing down the results or design the posters that summarize the findings [11]. A closer analysis of the work in two groups consisting of two girls and one boy in our study resulted in further interesting differences.

In both groups the boys use language that, at least potentially, leads to domination. They use instructions, for example, and avoid questions that might reveal that they are also unsure about how to explain the phenomena observed. Their questions are rather procedural. They also have a certain controlling function over the pace of the working process. They provide answers and explanations. They also tend to use imperatives and instructions like '*forget it*' or '*think it over*'.

The girls, in contrast, raise questions about the content investigated, they reveal their uncertainties about understanding the observed phenomena and they try to overcome these uncertainties in discussions. They use imperatives and instructions much less often than the boys.

There is another interesting difference. The boys tend to look for concrete solutions to the problem while the girls look for possible 'fields' where they might find a solution. They do not present a solution right away, but think aloud about possible ways to solve the problem and invite the other members of the group to participate in their ways of thinking.

In summarizing our findings it is first noteworthy that in both groups we observed that the girls participated to a certain extent in the construction of meaning as equal partners, despite the tendency of the boys to dominate. However, it is also fair to state that the communication seems to be more 'concrete' if the boys manage to dominate the interaction. Then talk is about facts rather than about uncertainties, guesses and 'half understandings'. But the boys' dominance also reinforces the disparity between boys and girls in further establishing the game 'girls ask—boys answer'. This linguistic pattern supports the impression gained by the teacher and the students, that on the one hand the girls know less, and are less competent, and that on the other hand the boys *are* competent.

The use of everyday language

Studies [4] have demonstrated that girls continue using everyday language for a longer time than boys. There is also evidence from research that understanding may be hampered if physics terminology is introduced too early [12]. Our transcripts show that it is particularly important for the girls to have the chance to formulate their initial ideas and thoughts freely in small groups, and to develop their thoughts by writing, which gives them the opportunity to formulate their ideas in the technical terminology of physics.

The use of concrete situations in examples and arguments

Already Gilligan [5] has noticed that girls think about concrete situations in a more personal way,

rather than in concise, abstract and idealized rule systems. This becomes linguistically apparent in their much more prevalent use of elements which point to themselves and their environment (here, now, I, you). There are a number of examples of this linguistic behaviour in our transcript. The boys tend to start with abstract terms; frequently the girls' starting points are their own feelings and the movements of their body.

The following example demonstrates this form of thinking: Within a whole class discussion a boy and a girl look for examples of chaotic behaviour.

> *Boy:* ... when a star explodes, then the gravitation is changing and this influences the curve of the planets. Another example: if one is skiing downhill on a route full of humps, if one is falling down then, one does not know in which way one will fall....
>
> *Girl:* If now YOU are falling down a staircase, you cannot predict where you will fall.

Anthropomorphisms

It is well known from studies on conceptions of science phenomena that students quite often use explanations in which the behaviour of certain sets of objects is interpreted in terms of human behaviour. This kind of analogy appears to be typical of human thinking. The German science educator Wagenschein [13] is of the opinion that anthropomorphic formulations appear not only in the first phases of science lessons but whenever the process of understanding is set into motion. Gender differences are not discussed in the literature on anthropomorphic speech, to the best of our knowledge. However, our transcripts indicate that anthropomorphic formulations are almost exclusively used by girls, and that girls use this form of analogy again and again. These findings are in accordance with the tendency referred to above of girls to speak about concrete situations in a more personal way than boys.

In the situation of learning about the chaotic behaviour of a pendulum, for instance, the pendulum is seen in analogy to a person, and the chaotic behaviour of the pendulum is viewed in analogy to the actions of a person. The girls talk about the pendulum, which '*cannot decide*' where it should move, and try to explain, for instance, the strange behaviour by saying '*it seems to like the colour yellow*'. This kind of thinking might be seen as an intermediate state, which leads them to correct solutions. This becomes apparent in the following episode: Three girls discuss the physical entities that influence the movements of the pendulum. One girls states:

> That it overcomes what the pendulum actually does; that means it influences the movement of the pendulum only because the force is bigger than the will of the pendulum, but we cannot write it like that.

In the following the three girls 'translate' the 'will' into 'force' and approach the correct explanation step by step.

Summary: boys and girls hold different notions of understanding

Table 1 summarizes the major findings of our study. The differences presented in the table may be explained by the hypothesis that boys and girls hold different notions of what it means to understand physics (see figure 2).

It appears that girls do not think that they understand a concept until they can put it into a broader (non-scientific) context. In particular, they try to understand the relations of the system of physics to the world as a whole. (Thus, the girls' understanding is located between the 'world' and the 'system of physics' in figure 2; the understanding is identified with the links that are established between the two. The more links, the more the girls feel that they understand.)

Boys, in contrast, tend to accept physics and technology as valuable in themselves. They appear to be more interested in the *internal* coherence of physics (and technology) whereas the girls tend to look for an *external* coherence as outlined. It seems that boys, for instance, do not need to view the physics (and technology) formulas in terms of their relations to the world as a whole in order to get the feeling that they have understood them. (Thus, their understanding is identified with physics itself in figure 2. They feel they understand something if they can assign it a place within their developing conceptual space.)

These differences are in accordance with findings of other studies that girls tend to

Table 1. The major findings of our study.

Girls	Boys
Teachers' questions and students' answers	
Open questions are more frequently answered by the girls...	...closed questions answered more frequently by the boys.
Girls' answers: complete sentences, in everyday language, without using physics technical terms.	Boys' answers: half sentences, clipped telegram style, use of technical terms.
Social and verbal behaviour in group work	
More frequently ask questions of the content in question. Reveal their uncertainties. Like to overcome them in discussions.	Ask questions how to further proceed in the process of making sense of a phenomenon. Hide their uncertainties. Use imperatives and instructions more often.
Relate physics to their everyday knowledge (use everyday language). Speak in a personal way about concrete situations, and use anthropomorphic explanations more often.	Move into the framework of science (use scientific terminology).
Look for possible fields where they might find a solution.	Tend to look for concrete solutions to a problem.

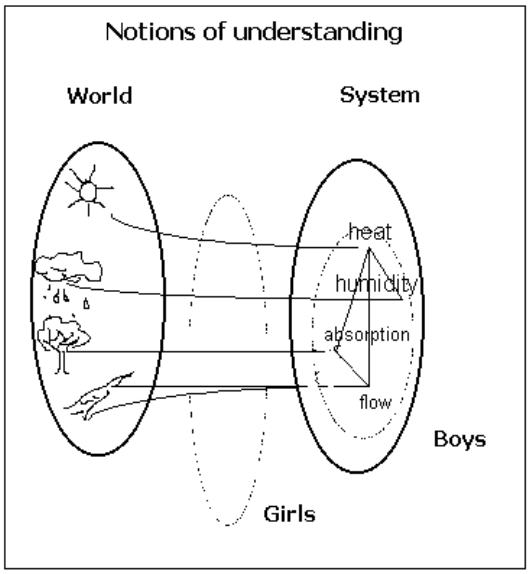

Figure 2. Notions of understanding.

prefer integrative kinds of thinking that avoid alienation from their everyday experiences [14]. It is also possible to view the differences from another perspective. Children tend to pose many 'why' questions and want to know the *reasons* that cause a particular phenomenon. Physics, however, provides only 'how' answers, i.e. it offers explanation systems that allow us to predict *how* a process will run. The hypothesis of different notions of understanding hence may be interpreted as more challenging for boys than for girls to play the game of physics, so to speak. Reasons may be that knowledge in physics is a factor that raises the status of a boy, e.g. in his peer group. Moreover, physics and technology are important fields for thinking about a future career, whereas many girls have already rejected jobs in these fields before starting their physics education at school [15]. However, girls' notion of understanding is to a certain extent more ambitious than the boys' aspiration of understanding. They are not satisfied by the sense an explanation makes within the systems of physics but demand sense in a more inclusive way.

Two remarks are needed here. Firstly, we do not claim that every girl and every boy fits nicely into the outlined categories of girl- and boy-like behaviour. There is only a tendency—albeit a significant one—for a particular girl or boy to hold a certain notion of understanding. Secondly, the framework of different notions of understanding has been developed based on the

literature on gender differences and on the basis of an exploratory study. We provide only preliminary findings that should be further investigated in subsequent studies. However, we think that the findings gained so far are so promising that in closing this paper it is justified to outline some consequences for science instruction.

- *Teachers' questions:* Teachers need to be aware that open-ended and closed questions address either girls *or* boys. They need to use both types of questions in a balanced way.
- *Group work:* If boys and girls participate in a group there is a tendency for boys to dominate the discussion. If this happens, group work is not efficient for girls. However, if the girls are self-confident enough to reject the boys' dominance the boys also benefit from the girls' participation as they foster open discussions.
- *Language and anthropomorphisms:* Girls and boys should be given the opportunity to formulate their ideas in everyday language and to use (personal) analogies and anthropomorphisms—not just at the beginning of the learning process. Girls tend to use (personal) analogies and anthropomorphisms more often than boys. They should be viewed as valuable starting points in the learning process.
- *Writing down ideas:* Girls tend to take the task of writing down ideas very seriously. It appears that this activity significantly supports the process of understanding science. Hence, enough time should be provided for that.

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