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Dear students, I would like to welcome you to my contribution in this series on "Empirical Research on Heterogeneity in Science Education". My name is Christoph Kulgemeyer, I am a physics didactic expert. This means that many of the examples I am contributing here are certainly taken from physics lessons, but from my point of view they are quite transferable. And my goal is to take a look at what can actually be said based on empirical research on this topic. In other words, to distinguish what we know from what we would like to know, from what we feel we can make a statement about. No, it's really about: What facts can we actually contribute to the current state of research?

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The goals I connect with this are, first of all, that you can name what measures exist for dealing with performance heterogeneity. And that is an important restriction - I am mainly concerned here with performance heterogeneity. That is certainly a very important dimension for specialised teaching. Then I want you to be able to derive conclusions for teaching from this, from these results. And finally, I would like to focus on external differentiation, internal differentiation and individualised teaching. And you should actually be able to take a critical stance on these three aspects. And I would like to give you a brief overview of the state of research.

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Why is this actually a question for natural science didactics? Isn't it rather a pedagogical question of how to deal with heterogeneity? Well, the answer is: Certainly, it also is a pedagogical question, but it is of course also a very central dimension for specialised learning for many different reasons, one of which is that the students attend your lessons with a certain prior knowledge. That may seem trivial, but the implication is: Each person sitting in that class obviously has a different level of knowledge about the subject that the class is supposed to be about. And that in turn means that the amount of information to be learned is individually different, if we assume normative learning goals. Clear conclusion.

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Students further differ in speed, in capacity of information processing, in cognition. You could almost, you could say they differ in intelligence, also of course in their interests. This also relates to the aspect that the pace of learning is very individual. That is also something you have to pay attention to, of course. And I have already mentioned the notion of interest, which varies greatly. When I think about my subject physics, there are always signs that physics is one of the rather unpopular school subjects. And for this subject, it is of course particularly important to take care of these points. How do you actually manage to arouse interest?

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Interest, however, correlates very strongly with how the learning effort is designed. And if I am interested in a subject, then I am understandably much more willing to explore this subject area, so I have a lower learning effort. It is also a dimension that one has to learn to deal with in the classroom. We can conclude that with a very identical teaching offer for all individuals, these differences increase almost automatically. So it tends to increase over the years of schooling, the gap widens. In educational research, they sometimes speak of the so-called Matthew effect - this is a passage from the Gospel of Matthew, which essentially says:

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To him who has, it will be given, and he will have in abundance. So what you already have determines to a great extent how quickly and how much you learn. We could now ask: Okay, with the same offer of lessons, these differences increase. Does that mean that the solution is to keep teaching as open as possible?

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Let's take a look at a special form of teaching about which we already know a great deal in pedagogical and subject didactic research, namely experimentation in natural science teaching. I would like to use this as a small example of a teaching situation to address the question of whether open teaching is the solution. A distinction can be made - differentiated by student activity - between demonstration experiments in class, i.e. when a teacher demonstrates an effect, for example in front of the class, we would say that this is a demonstration experiment, and the opposite on the other side of the scale of student activity, these are the open student experiments up to something like "Jugend forscht" - very, very open with own goals, which students can pick, and of course also their own ways of solving problems, certainly with advice, but largely in the hands of the students. And somewhere in between there are very closely guided teaching experiments, still carried out by the students themselves, with very clear instructions for action, step-by-step, as I have also shown here in this example. Where it is even shown in which masses you have to hang something on a feather. Because of these step-by-step instructions, the literature sometimes speaks a little disparagingly of so-called cookbook or recipe experiments.

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These forms of embedding experiments in physics lessons or also in natural science classes in general are connected to different hopes by the teacher, about what can be achieved through this. For example, with demonstration experiments: I hope that I can show it clearly and that everyone can see what is correct. I can highlight an effect precisely and perhaps also clearly refute the students' erroneous expectations about the outcome of an experiment. Yet, research on this suggests that this hope tends to be deceptive. Especially with concepts that have been experienced as very powerful in everyday life, this will not be the case. Students make different observations than the teacher intends. For teachers it is clear because from their prior knowledge they see exactly which effect they want to show. This is not the case with students. Here is a small example: If you connect a wire with a constant diameter to a voltage source and slowly turn up this voltage source, you will observe that this wire starts to glow everywhere at the same time. It has a constant diameter everywhere. However, students are often convinced that the wire starts to glow where, from their point of view, the current starts to flow into the wire, because that is where the effect must first appear. Now, as a teacher, I can demonstrate this experiment and still observe - as shown by Duit - that the students observe what they actually wanted to observe, namely that it starts to glow at the beginning. So this hope is actually deceptive.

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With open student experiments, as a teacher I very often have the hope: this is effective, this is interesting, because everyone has to act themselves, not just listen, they get to deal with these things themselves. Maybe I can even increase motivation for my lessons because they have to take action themselves. And what you can derive from the literature is that they are sometimes rather overburdened by the many parallel activities they have to carry out. So if you imagine it: You have to explore a new subject area, you have to organise yourself in a group, you might have to look at unfamiliar material first. These are all different dimensions in which learning has to take place. And if I now say as a teacher that I primarily want to illustrate a subject-related concept, for example, then it is perhaps not the right way to make demands in all areas at the same time. That can lead to excessive demands - and then, on the contrary, you even feel less motivated, quite likely.

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Could the golden mean be the solution here? The very closely guided student experiment? Here we say: Everyone is working in a focused manner, which surely means that everyone is also learning something. That is what we observe - very often. They work through the experiment instructions step by step and at the end they achieve the result that the experiment instructions were aiming for.

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Yes, in the literature it is often observed that they do indeed act very strongly, but do not connect any real goal with it. The quote "Very busy getting nowhere" is a very striking one, but it is quite accurate. They work through the experiment instructions step by step, but they have forgotten - very often - when you ask them what this experiment is actually about, what is the goal, what do we want to show with it? Then there can be no answer because they are so focused on the individual step that the overall concept is not becoming very clear to them. That is the great danger of this kind of experimentation, so that Hofstein and Kind summarised in an overview study: "The typical laboratory experience in school science is a hands-on but not a minds-on activity". So you act, you also observe the action, but that does not mean that you are also cognitively activated, that you think along. And learning, as we know, can only take place when you follow a train of thought there, when you are actually cognitively activated. Physical activity can be very deceptive. I do observe that they are active, but that does not mean that they are also thinking. And that is the dimension that really matters.

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What do we know about dealing with heterogeneity? How can we deal with this problem when we see that it actually becomes very complex even in this very limited teaching situation of experimenting? What can we say about this in general? First of all, you have to look at what usually happens in class and what measures are in place to deal with it. Here, too, we can draw up a scale, for example, of collaborative learning, i.e. a degree of collaborative learning. We would say: very little collaborative learning - that is external differentiation - something like the multi-tiered school system, but also additional offers. Internal differentiation is a little more collaborative learning, which means additional tasks or a variation of task difficulties depending on what the students actually need, but also simpler measures such as more support by the teacher when they walk around during group work and give some groups more attention than others, all this would be subsumed under this. And the extreme on this scale is completely individualised teaching, such as self-directed learning or learning diaries, which would be included in this dimension. And now you can look at it bit by bit: What do we actually know from the many empirical studies on how these individual measures actually affect students?

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First of all, let’s look look at the external differentiation. What is known about it? How does it work? The first study I would like to cite here is by Saleh. It examined whether dividing a group into subgroups with homogeneous performance or into subgroups with heterogeneous performance leads to different effects. This was done in such a way that groups of four were formed in each of five fourth-grade classes, which were assigned either to be homogeneous or heterogeneous groups. And then, for quite a long time, in fact 16 hours, lessons were carried out in the pattern of cooperative learning, so a very group work-heavy form of learning in this case. And then it was examined, with pre-tests and post-tests, how the students develop. And what we can observe is that the heterogeneous groups and the homogeneous groups actually show differentiated effects. We can take a closer look: The three groups of rather strong students according to prior knowledge, the rather average and the rather weak students develop very, very differently. In the heterogeneous groups, with the heterogeneous composition, the strong and the average students tend to learn less - but you can see in this big straight line that falls with the weak students, they learn even more in heterogeneous groups. They do not catch up - think of the Matthew effect, that would be very unlikely - but they learn much more than in homogeneous groups. The effect for the strong and the average through the homogeneous groups is rather small and that for the weak ones through the heterogeneous groups is relatively large. So one could say: low achievers benefit from heterogeneous groups, all others slightly from homogeneously composed groups.

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What does this tell you about the overall effect of external differentiation? Hoffer, for example, has studied the effects of dividing natural science and math courses according to performance level. It is rather something that we would call external differentiation, almost a multi-tiered school system. And what he finds in this study is an overall rather negative effect on subject performance for all groups. We almost suspected it: high achievers benefit very little from external differentiation, but they do benefit from it, so this is in line with the study I presented earlier - and on the other hand, this division has a major negative effect on low achievers.

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A similar picture is found in Ireson’s work. Ireson finds in an overall review, in which, relatively roughly calculated, all courses that had taken part in the central final examinations in England were divided into: Does the school have a concept that corresponds more to external differentiation or more to internal differentiation? And there Ireson finds slightly positive effects of external differentiation overall. Now in natural science, especially in mathematics and English, these effects cannot be found. But they are not significant either, so in the overall picture we can say: The tendency is to say that external differentiation has almost no effect on performance development.

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High achievers tend to benefit, low achievers tend to lose, but the picture is very mixed. What can be said, and this is also emphasised by Ireson, is that all students tend to benefit when the overall course is high-performing. This upward orientation seems to be an incentive for learning that is well worth considering and does not have to lead to experiencing oneself as unsuccessful and thus unmotivated. So external differentiation has almost no effect, if you can say that. We could say, why is there so much discussion about this, if the empirical facts show a rather mixed picture, but no clear results? Well, let us take a look at internal differentiation. What do we find there? First of all, across all subjects, so not focusing on the natural sciences, we do not see any clear picture as to what effect this has on subject performance in terms of performance heterogeneity, but presumably rather small effects. What we can also see, however: Positive effects in the non-cognitive area, for example in terms of motivation, that can be observed.

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There is a very interesting result in mathematics and natural science. Gruehn has examined in detail what effects internal differentiation measures have in mathematics, physics and biology and finds a negative effect on learning gains. A negative effect of differentiating measures, how can that be explained? Well, what Gruehn himself speculates is that differentiation takes up effective learning time. It takes time to establish such methods. It takes time to divide groups appropriately. And it is also the case that students need time to engage with it. And this time might actually be important for the positive effects in the non-cognitive area, but as far as subject learning is concerned, it might well be that there is this negative effect that Gruehn could identify. That would fit in with the fact that we know that a teacher's attention is something very, very central, very important, conducive to learning. If the teacher gives attention to one group, this time is logically lost to other groups. However, all students benefit from the learning effect of attention and this could actually explain why this negative effect is observed there – this time especially for the natural science subjects.

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Well, concerning the big picture we have to draw the conclusion: It is probably more important that the learning process is well structured overall. And these individual changes that I have just described are more on the surface of teaching: How do I compose groups? Am I doing more student-centred work or am I trying to keep control in the classroom? These are changes on the surface. And what becomes apparent is that these changes on the surface hardly explain whether a lesson is successful or not. So, is a well-structured lesson that pays close attention to guiding a learning process, that focuses on cognitive activation, the key?

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We can add a look at individualised learning to try to get a complete picture. What can be found is that with completely individualised learning, there are even tendencies toward a negative effect on motivation. This is often explained with people no longer feeling socially involved. You might be thinking of self-efficacy theory and that feeling socially integrated is a very important aspect of motivation. With strong individualisation, this can indeed be an aspect worth considering. What also needs to be emphasised is that this implies a very high diagnostic competence of the teacher.

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And likewise, the picture seems to be that strongly self-directed learning can only be effective if certain strategies are learned, have been learned, and a certain prior knowledge is already present. You cannot expect to invent a complex new concept by yourself. This will usually fail.

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Bohl asks very pointedly: We can, "with a view to effectiveness, simply and pointedly ask whether the amount of time required is affordable and appropriate or whether they - i.e. the students - should not rather be occupied with subject-related tasks in the service of a high level of active learning time instead of with the administration and organisation of competence plans". So again the call to design effective learning time, to create cognitive activation, to engage with the subject matter.

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Well, we could say: Subject-related learning is not everything. But it is also a dimension that is very important for subject teaching. Let's remember the results on experimentation, that aligns very well with what Hofstein and Kind also formulate as a message: Minds-on, not only hands-on, that is the surface of teaching, they act, we want to look at the deep structure, that they are actually cognitively activated in the learning process.

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Well, is direct instruction an option perhaps? Many meta studies reveal direct instruction as the most successful teaching concept for subject-specific learning. What we have to say quite clearly at this point is that we have to explicitly distinguish this from teacher-centred lecturing, in which the teacher is the sole focus. It is more like a sequence of well-conducted explanations, but enriched with appropriate learning tasks in which students must deal constructively with new knowledge by themselves. It is highly structured teaching, and this structure is provided by the teacher, but with open objectives. Review studies such as the one I have just presented, for example "What really works in special and inclusive education", show that structures seem to be particularly valuable for children with special needs. Structures seem to be very, very important especially for high-achieving students.

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Alright, clear messages are needed here - I have drawn a very mixed, very differentiated picture of the research landscape. What conclusions can we draw from this for teaching activities?

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What is important, and this must be said clearly, is a good deep structure of teaching. It is not so important what happens on the surface. And this deep structure is essentially determined by three aspects: A high level of cognitive activation - in other words, you have to get the students to think about the subject matter, a high level of constructive support, both emotionally, motivation-related, and subject-related when developing mental models. And successful classroom management - creating a focused learning atmosphere, creating a high effective learning time, that seems to be essential for subject-related learning. And that connects to the pictures we have just shown. Weak students in particular very often do not manage to give themselves the structures they need for successful learning. You have to give them these structures and that is actually a very important principle for all teachers. Structures have to be offered by teachers.

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Another important principle is that we obviously have to adapt to what is found in the students. Adaptation is a guiding principle of all teaching, which has very positive effects. It is about diagnosing what level you are dealing with and taking appropriate action. It sounds trivial at this point, but it is incredibly difficult. It requires a high level of skill, and at this point we can perhaps only say: Not everyone can teach. It is something you have to learn. But the good news is that it is something you can learn.