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Growth Mindset In Physics: Students' Beliefs About Learning Physics In Middle School And How To Foster A Subject Specific Growth Mindset

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Abstract

Students hold different beliefs about the nature of intelligence. While some believe in intelligence as a fixed trait (fixed mindset), others believe in a more malleable nature of intelligence that can be actively developed (growth mindset). These often unconsciously held beliefs can influence students' engagement in learning and (therefore) their academic performance. Especially when facing difficulties and/or overcoming setbacks, a growth mindset helps students' engagement. Students with a growth mindset focus on the learning process, while students holding fixed beliefs feel like they will never be able to master the difficult tasks and tend to give up more often. While most of the mindset research targets students' general academic mindset, we focus on their physics specific beliefs. Physics is described as 'challenging' and 'difficult' and in Germany, most students choose to drop physics as soon as possible. We designed and evaluated a physics specific mindset questionnaire, asking students not only about their beliefs about intelligence, but also about their beliefs about learning physics and their (potential) giftedness in physics. The results of this survey show that students' physics specific mindsets change over time, without targeted interventions. When physics classes begin, in middle school, a majority of students hold a growth mindset in physics, this percentage decreases drastically during the years of learning physics. Aiming to support a growth mindset in physics, we designed a subject-specific intervention based on the domain-general growth mindset interventions, that we tested in a pilot study with 24 students.

Motivation And Theoretical Background

Some students believe that they cannot learn physics unless they have a certain giftedness. Others believe in the possibility of developing their abilities regardless of any innate talent. In a more general discussion these beliefs are called mindsets or theories of intelligence (Yeager & Dweck, 2020). Research shows that students differ in their beliefs about the nature of intelligence. If they agree with statements like 'You have a certain amount of intelligence, and you can't do much to change it.' (Dweck, 2000), they are classed as holding a fixed mindset. If they disagree, they are described as holding more of a growth mindset. These - most of the time unconsciously held - beliefs influence students' engagement in learning and can even affect their academic performance. Students with incremental beliefs about intelligence and ability show a preference for challenging tasks. They tend to choose learning goal tasks over performance goal tasks and show a mastery pattern of behaviour (Blackwell, Trzesniewski & Dweck, 2007; Yeager et al., 2019;). Having a growth mindset influences motivational attributes, that support behaviour and can therefore increase academic outcome (Dweck, 2000).

As long as students are successful in school it has no great effect if they hold fixed or growth beliefs. But when faced with difficulty and setbacks, students with a fixed mindset tend to give up and avoid challenging tasks while students with a more growth mindset are more likely to engage in overcoming difficulty and focus on their learning process. Some studies show better academic performance (Paunesku et al., 2015), others a higher chance of taking on challenging tasks (Rege et al., 2021). Furthermore, there is also research on brain activity (Mangels, Butterfield, Lamb, Good & Dweck, 2006) while receiving feedback: people with a more fixed mindset are more interested in whether they did a task right or wrong but less in an analysis on strategies or improvement options. People with a growth mindset showed more brain activity in this qualitative feedback. Overall, having a growth mindset is considered supportive in the academic context.

Still, there is the question: which conception is the biologically correct one? The idea of growth for intellectual abilities is based on neuroplasticity. The human brain is able to form new connections between neurons and therefore build new networks or strengthen existing ones. The better cross-linked a part of the brain is (for example for solving mathematical equations), the easier it is to solve tasks in this area. Every time someone trains these abilities, the neuronal networks get stronger (Berlucchi & Buchtel, 2009). However, there is also a heritable component, and due to this, some people have better initial conditions for training their neuronal networks, for example in mathematic ability (Skeide et al., 2020). It is one of the most common misconceptions of growth mindsets: holding and promoting a growth mindset does not mean that everyone can excel in every field of expertise in the same way, but that no matter how trained someone is in a certain area at a time, they can always improve their abilities (Yeager & Dweck, 2020).

The main part of current mindset research is focused on mindset interventions, creating and testing effective programs for students (in high school and college) to strengthen their growth mindset beliefs and benefit from the correlational effects. Although there is no gold standard established yet (Burnette et al., 2022), Yeager et al. (2016) carved out the most important elements of a growth mindset intervention: scientific background of neuroplasticity in a memorable metaphor (key message: 'you can grow your intelligence'), stories from students making experiences relatable and a 'saying is believing' exercise. Students participating in a growth mindset intervention designed by Yeager and colleagues learn about neuroplasticity and that their brain can 'grow like a muscle'. They learn how this knowledge helped other students and they have to give growth-mindset-based advice for the next generation of students. In a very condensed 25-minute self-administered course, over 6000 students participated in a representative study - the National Study of Learning Mindsets (Yeager et al., 2019) - and the researchers could report small but significant effects on academic performances for low-achieving students.

Most of the mindset research addresses beliefs about general intelligence and academic abilities, however there are some studies looking at subject specific mindsets. This seems even more relevant since there are reports about different mindset distributions across varying contexts (Hong, Chiu, Dweck, Lin & Wan, 1999; Yeager, Trzesniewski & Dweck, 2013). Especially in the STEM field a more fixed view on intelligence is noticed which is also noted in similar psychological concepts such as talent habitus (Archer, Moote & MacLeod, 2020; Leslie, Cimpian, Meyer & Freeland, 2015). Research on these domain-specific mindsets often simply replaces 'intelligence' with 'physics ability' (see Zeeb, Ostertag and Renkl (2020) and for an overview of mindset studies and their measurement instruments see Sisk, Burgoyne, Sun, Butler and Macnamara (2018)). Considering this, looking closer at mindset and its characteristics in domain-specific contexts seems important and so our research focuses on students' beliefs about physics: How can students' physics specific mindsets be described and identified and can a student-facing intervention foster a growth mindset in physics?

This Research

Physics, our domain for investigating students' mindset, is one of the most unpopular school subjects in Germany. A lot of students drop out as soon as possible and there are only a small numbers of students who feel comfortable taking advanced courses in physics (Heise, Sinzinger, Struck & Wodzinski, 2014). It seems like an acceptable reason to claim, that you are just not smart enough for physics (Leslie et al., 2015; Slaughter, Bates & Galloway, 2011). Students in Germany start physics lessons in seventh grade (students are around 12 years old), in their third year after elementary school. After four or five years of physics classes (depending on their type of secondary school), they can drop the subject or choose basic or advanced level courses.

In this paper we present two studies. The first study is a profile study of students' beliefs about physics in middle school. Based on our findings from this profile study and our other cross-sectional study data sets (Goldhorn, Wilhelm & Spatz, 2022a; Goldhorn, Wilhelm & Spatz, 2022b) and the existing literature on mindset interventions, we developed physics specific learning materials to foster a growth mindset in physics. The new material was tested in a pilot study with a grade 8 (ages 13-14 years) physics course.

Profile Study: Physics-specific Mindsets in Middle School

For learning about physics specific mindsets, we developed and evaluated a mindset questionnaire. It consists of 15 items on three scales, with students deciding on a 6-point Likert-scale if they agree or disagree on statements about general intelligence, giftedness in physics and the impact of effort in physics.

Table 1: Items and reliabilities of the physics specific mindset questionnaire (Goldhorn et al., 2020).

Scale	Number of Items	Cronbachs α_C	Example
Theories of Intelligence	4	.80	You have a certain amount of intelligence and really can't do much to change it
Giftedness in Physics	4	.81	You need a certain giftedness for being successful in physics.
Effort in Physics	7	.83	Everyone can understand physics, you just have to put in enough effort.

* The original German Version of the questionnaire is accessible here: *http://www.thomas-wilhelm.net/Mindset-Fragebogen.pdf*

The first scale is a translation of the 'implicit theories of intelligence scale' from Dweck (2000). It contains four items, two fixed-mindset-statements and two growth mindset statements. The other two scales from the questionnaire are based on students' beliefs about learning and succeeding in physics. In an interview study (Spatz & Goldhorn, 2021) students were asked if they believe in an innate talent for being good in physics, if and how effort and strategies can compensate for talent and how one can notice if a person has giftedness in physics. From the

students' most common statements, the two scales 'giftedness in physics' and 'effort in physics' were conducted to create the mindset questionnaire. The questionnaire has been validated with $N = 244$ students (Goldhorn, Wilhelm, Spatz & Rehberg, 2020). The reliability of all three scales can be considered 'good' with values of Cronbachs $\alpha_C \geq .80$. See table 1 for the explicit values for each of the scales.
In the current study $N = 810$ middle-school students filled out the mindset questionnaire. 52.7 % of the participating students were female. In Germany there is a three-tier school system after elementary school and for this data set, we had 12 participating schools, covering all the three tiers.

In contrast with most mindset surveys, our questionnaire has more than one scale to separate growth and fixed mindset at a domain-specific level. To measure these, we did a cluster analysis using Ward's method with squared Euclidean distances. The cluster analysis allowed us to identify four types of students: students with a growth mindset have higher mean values of 4 or more in all three scales, so they neither agree with intelligence as a fixed trait nor a certain giftedness in physics as a predictor of learning physics, rather they see effort as one key to success. Aside from the *growth mindset in physics*, we identified two types of fixed mindset. The first we called *fixed mindset 'general intelligence'*. Students holding this fixed mindset agree with statements like 'intelligence is a fixed trait' but do not think there is a special giftedness in physics necessary. The other fixed mindset type is the *fixed mindset 'giftedness in physics'*. Students with this physics-specific fixed mindset are more neutral in relation to the question, as to whether intelligence is fixed or malleable, but they (strongly) agree with the idea that giftedness in physics is necessary for succeeding in this subject. So, this mindset can be understood as the domain-specific fixed mindset. All students who do not fit in those three mindset types are clustered as *mixed mindset*. To make the assignment of students to our clusters possible for other researchers and studies, we adapted an assignment principle in the next step of analysis. Figure 1 shows the pathway to find the right cluster for each student based on our cluster analysis by just using the mean values of the three scales.

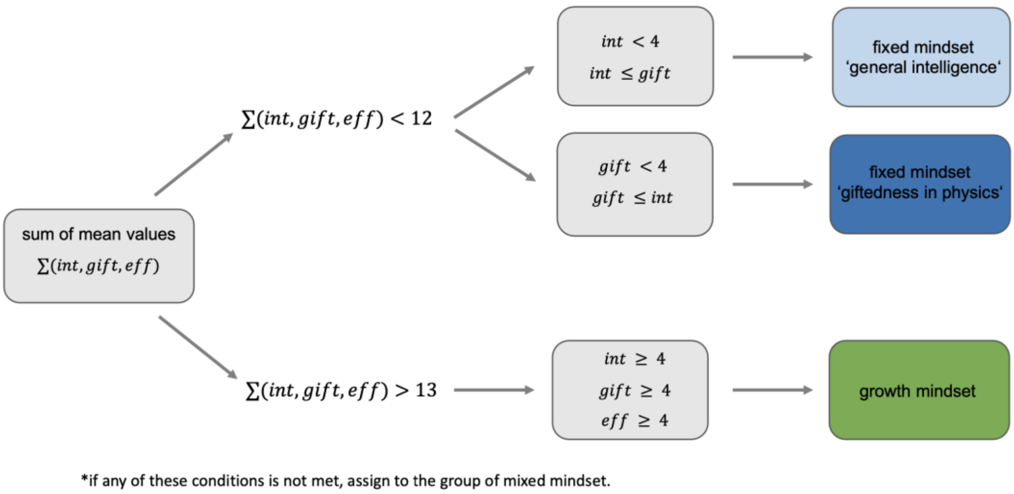

Figure 1: Pathway of assignment principle to assign students to one of the three physics specific mindset types (otherwise to the mixed mindset group). The assignment principle is based on the mean values of the three scales: theories of intelligence (int), giftedness in physics (gift) and effort in physics (eff).

Results

Using the assignment principle for the current dataset of $N = 810$ middle school students, 34.6 % of the participating students hold fixed beliefs, 18.5 % are assigned to the fixed mindset (general intelligence) and 16.1 % of the students are assigned to the fixed mindset (giftedness in physics). 39.5 % hold a growth mindset in physics and 25.9 % form the group of the mixed mindset, so they are not assigned to either one of the fixed mindsets or the growth mindset type. Further, we analysed the mindset distribution changing between students in grade 7, who have just been introduced to physics, and students in the following grades. Figure 2 shows the percentage of students holding a growth mindset in physics and figure 3 shows the development of the two fixed mindsets.

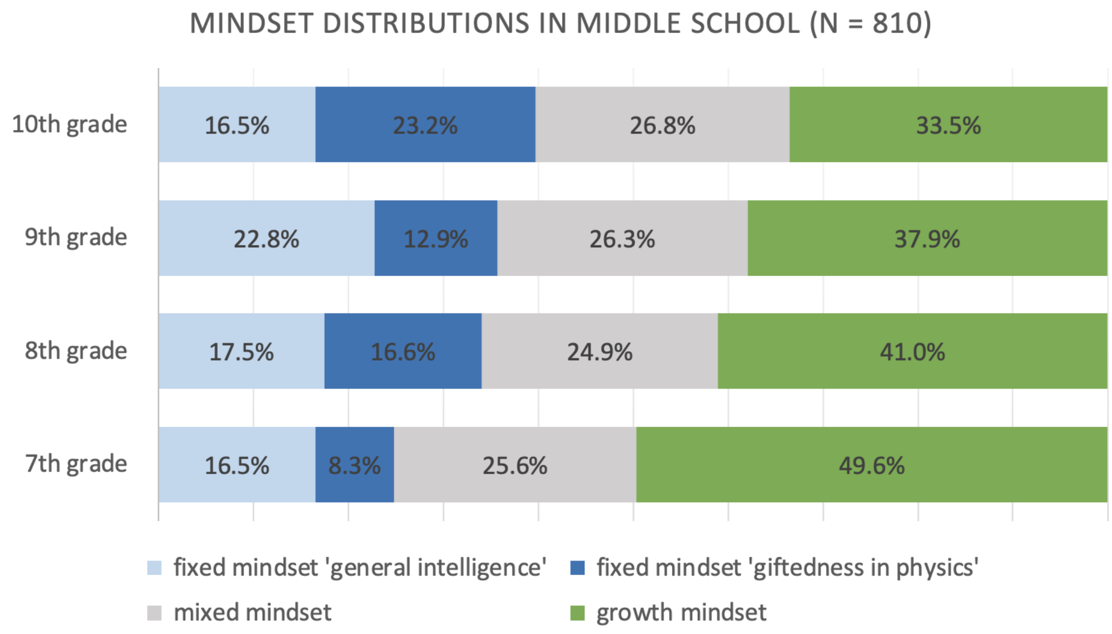

Figure 2: Percentages of students holding fixed or growth beliefs in physics for $N = 810$ students, sorted by academic year from grade 7 to grade 10.

In seventh grade, nearly half of the participating students hold malleable beliefs about physics (49.7 %), while only 8.3 % of the students in this school year are assigned to the physics specific fixed mindset. During the next three years the percentage of students with a growth mindset decreases to a minimum of 33.5 % in tenth grade. In the same school year 23.2 % of the students are assigned to the physics specific fixed mindset. Comparing the mindset distribution for female and male students (Figure 4), the percentage students assigned to the growth mindset in physics is nearly the same: 39.6 % of the girls and 39.4 % of the boys hold malleable beliefs. Also, the percentage of students assigned to the two fixed mindset types combined is balanced and shows no gender effect. But while 14.8 % of the female students hold general fixed beliefs, 22.9 % of the male students are assigned to this mindset type. And for the physics specific fixed mindset it is reversed: 11.6 % of the boys and 19.7 % of the girls hold fixed beliefs that support a giftedness in physics.

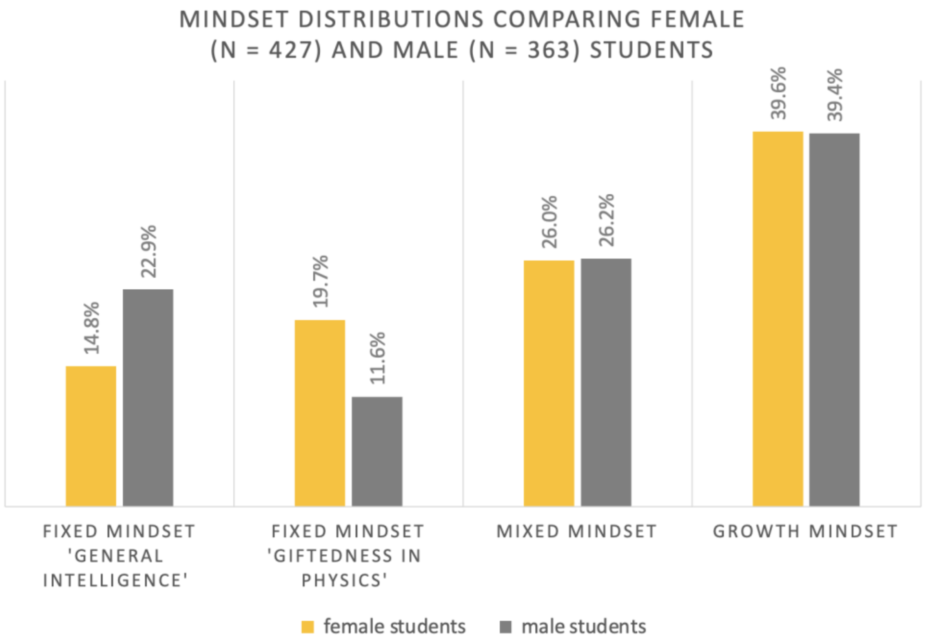

Figure 3: Percentages of students holding fixed or growth beliefs in physics, comparing female ($N = 427$) and male students ($N = 363$).

Discussion

The higher the school year in which the learners are in the lower the percentage of students with a growth mindset in physics. This development is also reported for incremental beliefs in maths (Gunderson, Hamdan, Sorhagen & D'Esterre, 2017) and domain general mindsets (Cheng & Hau, 2003). More strikingly, there seems to be a change of the number of students with physics specific fixed mindsets. This percentage increases from 8.3 % in seventh grade, when they are first introduced to physics lessons, to 16.6 % in the following academic year. After just one year of physics lessons, the number of students believing in the need for giftedness in physics for success has doubled. The same effect is observable if only taking the data from one school type (grammar school) (Goldhorn et al., 2022b). This could be indicating not only age-dependent development of mindset distributions, but a mindset shift influenced by the start of physics being taught in separate lessons, in comparison to general science lessons. There is research reporting stronger fixed beliefs in STEM fields (Meyer, Cimpian & Leslie 2015) and our data supports the hypothesis that these beliefs are consolidated during exposure to STEM classes. Looking for gender differences, girls seem to have stronger beliefs in an innate talent required for physics, while proportionally more boys hold general fixed beliefs. A similar observation is reported by Archer et al. (2020) and for other, belief-based concepts like self-efficacy (Lindstrøm & Sharma, 2011), but overall, there are no significant results in possible gender effects on students' (domain-specific) mindset.

An Intervention Pilot Study

Knowing about physics specific mindsets, their distribution and change during the first years of learning physics leads to the main question: how can a growth mindset in physics be encouraged? The physics specific fixed mindset, that differs from the general intelligence fixed mindset, bolsters our approach for subject specific research. So, just as we developed the questionnaire based on the common mindset questionnaires but with the addition of physics specific scales, our intervention is also based on the work of Yeager et al. (2016) but with an explicit connection to physics.

Design Of The Intervention

The intervention is self-administered and named 'train your brain in physics'. It is designed to be carried out in two back-to-back lessons of 60 to 90 minutes each. In the first lesson students learn about their brain and neuroplasticity. The key element of this part is the worksheet 'you can grow your intelligence' (Blackwell et al., 2007) that is part of growth mindset interventions since 2007. Since our research is in German, we used a translation of the text already used by Zeeb et al. (2020) in their mindset research. Students read the text about the brain being trainable like a muscle and highlight the main statements. After that, students are presented with information about how the brain grows by forming connections between neurons and how more of those connections allow easier access to knowledge.

The second lesson of the intervention is built around the learning strategy 'BRAIN' as introduced in the growth mindset program BRAINOLOGY™. BRAIN is originally used as an acronym for 'break it down, research, active learning, iteration, never give up' (MindsetWorks, 2002-2014). To make it work in German, we changed it a little bit to 'brainstorming, what do you know already on this topic, research, active learning, repetition, never give up'. Using the BRAIN-strategy supports the brain in forming new connections, i.e. it helping to strengthen the 'brain muscle'. After introducing the learning strategy, the students apply the BRAIN-method to a physics topic, making it domain specific. We chose a very popular experiment, the burning candle - rising water experiment. A candle is placed in a bowl with low level of water. After lighting the candle, a glass is placed over the candle. The candle goes out and the water level inside of the glass rises. This experiment is often introduced the first time in primary school, but the explanation is often oversimplified. There is a physical and a chemical part of the explanation: the candle needs oxygen to burn. Burning is a chemical reaction and the oxygen reacts to carbon dioxide and water. If the oxygen level inside the glass is lower than 16 %, the candle goes out. One common explanation is that the candle consumes the oxygen and the space of the oxygen is filled with water by raising the water level inside the glass. This explanation is lacking in several ways: first, the atmospheric oxygen level is typically 21% and the candle goes out when the oxygen level is lower than 16 %. Hence, the candle does not consume all the oxygen but only about one quarter. Second, the oxygen does not get consumed in the sense that it has 'vanished', but chemically reacts to form carbon dioxide and water. This product does need less space than oxygen, but the difference is much too small to explain the water rising. So, to explain the water rising, the physical part of the explanation is needed. The burning candle heats the surrounding air inside the glass. When going out, the air around the candle is cooling down and, following Charles' law, this leads to a decrease in required volume. To equalise the resulting difference in air pressure inside and outside the glass, the surrounding atmospheric pressure pushes more water into the glass, decreasing the volume for the air inside it (Plappert, 2012; Wiederholt & Plempel 1996). Students are first asked to write down what they remember. After that, they work through the correct explanation step by step and repeat it using different tasks (e. g. choose the right answer and completing sentences). If possible, the students get the opportunity to try or view the experiment, before working on this part of the intervention.

To finish the intervention, students are asked to reflect on what they have learnt about the brain and learning. Finally, in the last task they are asked to give advice to younger students who have just started learning physics ('saying-is-believing'-exercise).

Creating the physics specific growth mindset intervention involved a constant balance between matching previous general mindset interventions as described and evolved by Yeager and colleagues, while also making the transfer to the subject specific research and integrating subject specific best practice. Our intervention takes part in at least two lessons, so students learn the growth mindset message in two consecutive weeks. In the first lesson they work on the general growth mindset section (learning the brain as a muscle metaphor, neuroplasticity and the BRAIN-method) and then connect it to physics in the second lesson (applying the BRAIN-method to the candle burning, water rising experiment). The intervention contains the important elements conducted by Yeager et al. (2016): scientific information, stories from students (mainly worked in into the 'you can grow your intelligence' worksheet) they can relate to and the 'saying-is-believing' exercise in the concluding section when learners write their advice to younger students.

Method

To pilot our intervention material, we did a first study with one eighth grade class (13-14 year olds) (N=24 students, 12 of them female). The students filled out the mindset questionnaire in the beginning of the first lesson of the intervention and then they worked through the intervention tasks individually. We presented the intervention as a paper-based workbook with integrated spaces to do the writing tasks. The teacher was present and helped the students with the experiment and answered questions if there were difficulties in understanding the tasks. However, the teacher was not trained in mindset theory or instructed to teach the growth mindset message aside from the intervention. Two months after the intervention the students filled out the mindset questionnaire again. This timeline (instead of a traditional post-test at the end of the intervention) was chosen to focus on a possible mindset change. Immediately after the intervention we cannot presume an actual long-term change of beliefs but only do a manipulation check. And to avoid fatigue effects from our questionnaire, the manipulation check is part of the intervention, and the questionnaire is filled out only before and two months after the active intervention.
The study was conducted with whole classes and there were no personal data collected. To connect students' workbooks with their mindset questionnaires each student created an anonymous token.

Results

Since the participating group of students was only 24 and it was our main goal to evaluate the comprehensibility and estimated times for each task, there is no meaningful statistical analysis. All the students finished the intervention material within the estimated time and no feedback was received that learners did not understand any of the tasks. Of course, not every student answered the quizzes correctly or could explain the candle experiment, but every workbook shows the students engaged in work on the tasks. All the students did the important writing tasks and participated in both surveys. Consequently, the intervention material can be used in the following main study without further revision.

The last task in our intervention is a 'saying-is-believing'-exercise where students should give advice to younger students who start learning physics. The goal of this task is for students to repeat the growth mindset message in their own words to strengthen it, so this task could be viewed as a check if students comprehend the message of the intervention. One student wrote *"I would explain how you can train your brain and why it is important to take on the challenging tasks to strengthen the connections of your brain cells"*, another *"You should try to be focused and concentrated from the beginning and actively take part in every lesson, so you don't miss anything. Physics doesn't have anything to do with talent you are born with!"*. Most of the students wrote growth mindset messages in varying levels of detail. Some gave more practical advice, like *"ask, if you don't understand it"* or "*practice a lot and you will get better"*, some were more at an overall motivational level, for example *"if you stay engaged, you can train your brain and physics gets easier"* or "*keep trying the challenging tasks and* *ask, if you don't find the right solution. And never forget, physics can be interesting and almost always(?) makes sense"*. Some students explained in great detail, for example *"I would suggest staying positive and engaged. Because training your brain cells makes your brain smarter and increases your intelligence*" or *"you can train your brain and if you learn actively, you build your knowledge. With every repetition your brain builds new connection between brain cells and your brain grows in size and weight"*. Except for three students, all the answers on this task showed some aspects of the growth mindset message.

Before the intervention and two months after, the students filled out the mindset questionnaire. In the first survey already 19 of the 24 students were assigned to the growth mindset, which is an unusually high percentage. Two months later, these 19 students were assigned to the growth mindset as well. But there is a higher value on the theories of intelligence scale observable for 11 of these 19 students and a higher overall mindset score for 6 of these 19 students. Two students were assigned to a fixed mindset in both surveys and three to a mixed mindset. For those five students the growth mindset score was lower by the time of the second survey.

General Conclusion

Students' beliefs about the fixedness versus malleability of physics ability changed during the years of physics lessons. The belief in an innate talent increases, while the percentage of students with a growth mindset diminishes in size. Especially the fixed mindset 'giftedness in physics' seems to be intensified when students are faced with physics lessons. The percentage for this mindset type doubles between the first and second year of learning physics. To address this development and to strengthen students' growth mindset in physics, we designed an intervention based on the criteria for mindset intervention by Yeager et al. (2016) and connected the growth mindset message with a physics topic. We tested our materials and evaluated the comprehensibility of the different tasks, addressing students in their first years of learning physics. Due to the limitation of only N = 24 participating students we cannot make any statistically relevant conclusions about the impact of our intervention. But the small shifts in growth mindset scores from before the intervention to the second survey two months after the intervention are promising. It will be our next step to investigate the impact of the intervention on students' physics specific mindsets in our main intervention study with students from grades 7, 8 and 9 starting in February 2023.

Acknowledgments

Our study follows the ethical guidelines provided by the Germany Psychological Society (DGPs). The following statement includes statements on all the relevant ethical principles. The study is a no-risk research design for all participants, namely schools, teachers and students. Teachers are informed about the aims and the procedure of the study, the entire participation is voluntary for schools, teachers and students and there is the possibility of dropping-out at any time. All personal data is protected and collected only anonymized. Parents of participating students are informed about the study in advance and got contact information in case of any questions. The tasks for participating students are not part of the curriculum, teachers do not get informed about the individual responses of their students. Therefore, participating students do not expect disadvantage or evaluation of in case of dropping out. There are no incentives on participating in the study, except from the potential benefit and learning, that is object of the investigation. All participants are informed about the results of the study.

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