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Learning and performance do not have to come at the expense of socio-emotional development

1. Introduction

All subjects taught in school aim to foster meaningful learning and conceptual understanding. The knowledge acquired in the classroom is supposed to enable students to better understand the world around them, as well as to develop and achieve short-term and long-term goals. The reality, however often looks different: Students acquire knowledge that is bound to the narrow context of the classroom, which means they do not achieve a deeper understanding of the content dealt with. If at all, students can retrieve the knowledge in the next exam, but its isolated representation in long-term memory makes it unlikely to be activated in new contexts inside and outside of school (Mähler & Stern, 2006). This is detrimental for students, teachers, parents and society as a whole. It is particularly frustrating for students to experience day after day that they have to learn things that they do not understand and whose intellectual or practical benefits they cannot comprehend. These experiences will most likely create feelings of helplessness and belonging uncertainty (Cohen, 2022), which has a long-term impact on students' socio-emotional development and impairs their further academic development (Baumert et al., 2023).

Providing an education system that meets the needs of society and at the same time benefits the broad variety of learners, is one of the greatest challenges in the modern world. Scientific progress made in various areas related to learning and education can help to better understand the challenges of providing learning environments that support children in developing positive attitudes to performance and equipping them with self-efficacy. Three lines of research, which will be discussed in detail in this article, can contribute to this goal:

a) Preparation for future learning instead of short-term effects: Promoting the acquisition of usable and transferable knowledge. Schools were founded because skills such as reading, writing and arithmetic have evolved over the course of cultural development and need professional instruction to be passed to the next generation. Therefore, learning at school is by definition more demanding than the acquisition of skills for which evolution has prepared us. At the same time, we have not yet exhausted the opportunities for facilitating learning that the learning sciences offer us. By providing learning environments that meet the affordances and constraints of human information processing (Schumacher & Stern, 2022), learners are more likely to have successful experience and thereby gain self-confidence and self-efficacy (Yu & Schunn, 2024).

b) Creating motivation by promoting mastery instead of performance orientation: In contrast to everyday concepts held also by many teachers, for Psychologists motivation is rather a state than a trait. This means that learners' motivation can be influenced by teachers, and this does not have to be done by lowering standards. The self-determination theory (Deci & Ryan, 2012) provides the framework for this.

c) Managing diversity in cognitive abilities, prior knowledge, interest and social background. When entering a class, students do not start at the same level, and they often end up even more diverse. In particular, cognitive abilities as measured with intelligence tests are a stable personality trait with a strong impact on learning outcomes (Stern, 2017; 2024). Managing diversity to the benefit of all is a major challenge for teachers, which needs more attention.

2. Preparation for future learning instead of short-term effects: Promoting the acquisition of usable and transferable knowledge

Effective learning environments have to consider affordances and constraints of the human minds. Thanks to scientific progress in cognitive science, we now have a solid understanding of how the human mind works and how learning can be promoted. To avoid frustration among students and teachers, learning material and instructional interventions must consider how incoming information is encoded, stored and retrieved. In the interests of efficient learning environments, the multi-store model of human information processing agreed on by psychologists should be taken into account in all educational activities. Sensory memory is the earliest stage of processing the large amount of continuously incoming information from sight, hearing and other senses. In order to allow goal directed behavior and selective attention, only a fractional amount of incoming information passes into the working memory, which is responsible for temporarily maintaining and manipulating information during cognitive activity. The special architecture of working memory is one of the unique features of humans. What the cell is for Biology and the molecule is for Chemistry is working memory for Psychology, as this construct can broadly explain what controls human behavior (Stern, 2024). The limited capacity of working memory allows control of attention and thereby enabling goal directed and conscious information processing. Working memory is the gatekeeper to the long-term memory, which is assumed to have an unlimited capacity. Here, information acquired through experience and reasoning can be stored in different modalities as well as in symbol systems (e.g., language, script, mathematical notation systems, pictorials, music prints). Working memory enables intentional information processing by focused attention, but it can also process incidental information. The multi-store model of human information processing is not at all a one-way street, and long-term memory is not to be seen as a storeroom or a hard-disk where information remains unaltered once it has been deposited. A more appropriate model of long-term memory is a self-organizing network, in which verbal concepts, images, or procedures are represented as interlinked nodes with varying associative strength (Stern, 2017).

Working memory regulates the interaction between incoming information from sensory memory and knowledge activated from long-term memory. In case of very strong incoming stimuli (e.g., a loud noise or a harsh light), working memory activities will be interrupted. For the most part, however, working memory is guarding against incoming information to make sure that goals that have been set will be achieved appropriately. This means, working memory is continuously busy with selecting incoming information, aligning it to knowledge retrieved from long-term memory, and preparing responses for accomplishing requirements demanded by the environment. Inappropriate and unsuitable information intruding from sensory as well as from long-term memory has to be inhibited, while appropriate and suitable information from both sources has to be updated. These working memory activities permanently change knowledge represented in long-term memory by adding new nodes and by altering the associative strength between them. Working memory activities are intertwined with the context as well as with the knowledge stored in the long-term memory. One of the most important insights from the learning sciences is that prior knowledge is the most important predictor of future learning. Successful teaching means to provide learning opportunities that meet with prior knowledge.

Psychologists have agreed on distinguishing between declarative (knowing that) and procedural (knowing how) knowledge. Declarative knowledge can be communicated because it is represented on the basis of symbol systems (language, script, mathematical or visual-spatial representations). It is the basis for constructing meaningful conceptual knowledge through processes of inference and elaboration. In contrast to declarative knowledge, procedural knowledge can be directly applied to perform a task, and it includes motoric actions like driving cars as well as mental actions like algebraic transformations. Procedural knowledge emerges as a consequence of repetition, by which single actions become increasingly integrated into a coordinated series of actions. If the association between these actions is strong enough, they can activate each other and therefore only need a minimum of working memory functions. Because automated knowledge is at most partly open to conscious inspection, it can hardly be verbalized, and is resistant to modification. Mastery of any academic content area requires procedural and conceptual knowledge. Both kinds of knowledge are strongly intertwined (Schneider & Stern, 2010), but they are acquired through different mechanisms. Procedural knowledge is acquired by condensing single pieces of knowledge into broader units. The repeated execution of actions composed of single steps results in automated procedures. The repeated presentation of sets of small single stimuli may result in putting them together to a meaningful whole, which is called a chunk. Once chunks and procedures are created, they can be processed with low memory requirements. Transforming single letters into words is an example of chunking.

Conceptual knowledge, on the other hand, represents meaning, what can show up in classifications, principles, generalizations, theories or models in a content area. It can be communicated via symbol systems and it is constructed through reasoning that has been stimulated in interactions with other individuals, written material or other media. Engaging with content in this way is a challenge to working memory – in particular for areas that are mainly based on abstract concepts, as it is the case for many STEM areas.

How to promote usable knowledge

The goal of academic learning is the acquisition of usable knowledge that is flexible enough for transfer and problem solving. Usable knowledge is composed of procedures and chunks to relieve working memory functions which can then be used for grasping the gist of a problem. Content areas and academic disciplines differ in the composition of both kinds of knowledge, and this may affect the importance of intelligence for achieving expertise. Typical areas of expertise which are primarily characterized by the formation of chunks are reading and chess. Learning from texts is effective if working memory resources are available for processing the content instead of decoding letters. Experienced readers have chunked letters into words and patterns of words and therefore can concentrate on the content. Expertise in chess is gained by chunking single chess positions into broader units which can be recognized and stored with minimum working memory resources. Also, in broader disciplines, chunking is essential and reflects expertise. The audience of my lecture on "Human Learning" are master's students from different STEM areas. To demonstrate the impact of prior knowledge on memory, I show my students pictures presented in Figure 1

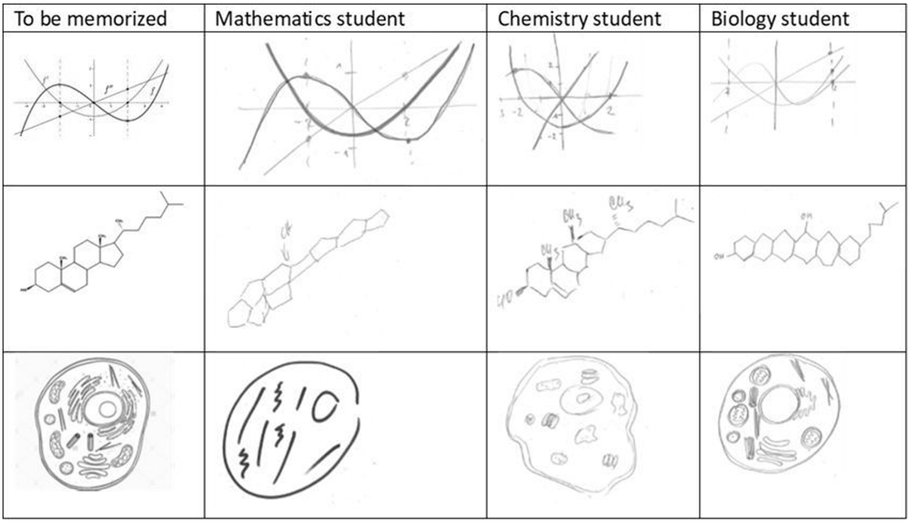

Figure 1: The pictures presented in the left column present important concepts from Chemistry (cholesterol molecule), Biology (animal cell) and Mathematics (first and second derivative of a polynomial function). The pictures were presented for a few seconds to STEM students with different disciplinary backgrounds, who were asked to draw them afterwards. Examples of the drawings from the students are presented in the cells to demonstrate the importance of prior knowledge for memorizing complex information.

for a few seconds and then ask my students to draw them. The pictures represent concepts that make sense to experts in the field, while being more or less random to others. This becomes obvious in their drawings. Depending on their disciplinary background, they either reproduce the image exactly or provide a rough sketch that lacks key conceptual features.

Automated procedures and chunks are necessary but not sufficient for mastering broader academic areas. STEM disciplines as well as humanities are cultural achievements and mastering them means understanding statements expressed in symbolic systems such as language, writing, formal notations, pictorial and graphical representations. Competence is evident in these areas by building a network of interconnected but distinct concepts, which provide the basis for deductive, inductive, and analogical reasoning. Such cognitive processes enable transfer of knowledge to new situations and problems, which is a challenge for all learners, no matter how intelligent they are. The difficulties have been best explored in mathematics and the natural sciences, especially in physics. Here students not only have to learn new concepts, as it is the case for all academic fields, but they must also restructure the meaning of many expressions used in daily life, among them concepts like force or energy. Mathematics is based on theorems and relations between numbers and figures that are derived by deductive reasoning.

Learning environments are effective if they meet with students' prior knowledge and address learners' deficits either in terms of conceptual misunderstandings or in terms of a lack of chunking and automation. In the past decades, learning sciences have developed and systematically evaluated so called means of cognitive activation that can be implemented in instructional units. These means have in common that they intend to face learners with deficits and misunderstandings regarding their prior knowledge (Schumacher & Stern, 2022). Presenting learning material that requires systematic comparison between superficially similar but conceptually different situations can help to extract abstract concepts. Prompting self-explanations or asking metacognitive questions raises learners' awareness of their prior knowledge, including deficits and misconceptions. Thanks to progress in digitization, teachers now have methods like formative assessment at their disposal which allow them to diagnose their students' deficits and provide them with appropriate learning opportunities. A second grader may answer "7" when asked: "What is a quarter of 32". A teacher may conclude that the student does not master multiplication tables properly and therefore asks the student to just practice. However, by asking the student to explain why he ended up with seven may shed light on severe conceptual deficits: "A quarter is always 25, and 32-25 results in 7". In this case, the concept of "quarter" has to be addressed. "Knowing what students know" is the key to better adapt learning opportunities to students needs and saves a lot of frustration for students and teachers. This kind of cognitive empathy on the part of the teachers can be expected to promote students' social-emotional development.

3. Motivation: Promoting mastery instead of performance orientation

Many teachers complain about their students' lack of motivation, as they have the feeling that no matter what efforts they make, students are not willing to get involved. At best, they develop extrinsic motivation, i.e. they work towards passing the exam or getting the best grade with minimal effort. Such experience suggests that motivation is a fixed individual characteristic rather than a malleable state. Such attitudes are supported by messages delivered by some psychologists, e.g. by Duckworth et al. (2019), who emphasizes that a student's grit – their passion and perseverance for long-term goals – is decisive for her learning outcomes. Precondition for developing grit is to develop passion and interests and to cultivate deliberate practice. The emphasis on passion and interest is also in line with an attitude held by many teachers (Lazarides et al., 2023). What all these beliefs have in common is that they see the causes for a lack of motivation primarily in the learners, which is of course a relief for teachers. However, motivation research has a much more differentiated view, which considers the context in which learning takes place. While intrinsic motivation is a desirable goal, it would be unrealistic to expect it in every subject at any time. Students have developed their own pattern of interests and time allocation, which is at least partly desirable because they have to pave the way for their career paths. Rather than expecting students to enter the class with intrinsic motivation, teachers have to be prepared for less enthusiastic learners. Learning opportunities can be designed in such a way that students engage with the content, even if they are not too enthusiastic about it.

The Self-Determination Theory (SDT) from Deci and Ryan (2012), which emphasizes the importance of conditions supporting the individuals' experience of autonomy, competence, and relatedness, provides a framework for designing such learning environments. Learners' autonomy is violated if they have no idea of the benefits from participating in the curriculum, either in practical terms or in terms of intellectual insights. By starting a learning unit with a question that cannot be answered initially but will be so at the end can contribute to the feeling of autonomy. Also, giving learners some freedom to choose among the elements of the learning unit (e.g., problems to work on, texts to read, experiments to do) can increase the sense of autonomy. Learning is hard work and can be exhausting. Experiencing progress is key to maintaining the motivation to focus on further progress. Constantly experiencing failure is frustrating and will likely make students give up. Tailoring practice problems to students' achievement level allows them to make progress with some effort. Applying means of formative assessment can help to support mastery instead of achievement orientation in two ways. First, it allows teachers to identify students' difficulties and to present tailored problems, and secondly experiencing that teachers are interested in students' state of knowledge without judging it gives feeling of relatedness (Lichtenberger et al., 2024).

4. Managing diversity

In the early 20th century, a pragmatic need for predicting the learning potential of individuals initiated the development of standardized tests. When compulsory schooling had become common more than a century earlier, the tremendous differences in learning potential became obvious. The need for a qualified workforce led to an extension of higher education and required valid and reliable forecasts of performance potential in as yet unknown areas. Reasoning abilities, as they were tested in intelligence tests, revealed stable individual differences. Intelligence is now understood as a polygenically inherited uniform personality trait with a high reaction norm, which follows the normal distribution, and which has a strong impact on the use of learning opportunities, and which explains individual differences in numerous outcome measures (Stern, 2017). In the past decades, numerous intelligence tests have been developed and standardized, appropriate for different diagnostic purposes, among them in educational contexts. Moreover, tremendous progress has been made in explain the neuro-cognitive foundations of differences in intelligence, which also have implications for educational decisions. The progress made in basic as well as in applied psychology calls for the education system to be analyzed in the light of intelligence research.

4.1 Intelligence and educational choices

Different from the Anglo-American world, in Central Europe standardized reasoning tests are rarely ever used for educational decisions beyond admission to special education programs. In the US and the UK, standardized university admission tests that show high correlations with intelligence tests. The same was formerly true for the admission to the grammar school in the UK, which was regulated by the 11+ examination. In central Europe, admission to the university is still mostly regulated after elementary school by assignment to academic track schools (Gymnasium), and the decision is mainly based on grades and parents' request. Those who do not go to the Gymnasium (depending on countries and regions [50–80 %]) go to regular schools supposed to prepare for vocational education. While intelligence-based tests are rarely ever directly used for educational track choices, the substantial correlations between school grades and test scores of r = .50 (Roth et al., 2015) raise the question, to what extent intelligence indirectly prevails. In recent decades, numerous studies have revealed a considerable impact of the family background on educational trajectories, which is often more important than cognitive competencies, as many studies show (Blossfeld et al., 2016). Such trends are neither compatible with the values of a meritocratic society, nor do they raise hopes for economic stability and innovation. Considering the stable differences in cognitive abilities in the overall school system as well as in concrete classroom practice is a permanent challenge in education that has not yet met with much success.

Meeting the different needs of a heterogeneous group of learners is inevitably accompanied by under- and overload for many learners. Ability-grouping on the other hand goes along with misallocation, as even the best tests are far from perfect in terms of validity and reliability. Giving everyone the opportunity to realize their potential without setting the course too early must remain the goal. Intelligence tests can help with this, but their informative value should not be overestimated. Individual differences in learning potential are already obvious in primary school, where the focus is on basic cultural competencies like literacy and arithmetic supposed to be mastered by almost all members of a society. However, even if this goal is reached, differences in the time needed to achieve a particular performance level are obvious. From elementary school onwards they can be traced back to differences in more general cognitive capabilities (Schneider et al., 2014). At some point, it will no longer make sense to teach pupils together. This will be the case at the latest when more demanding content is on the agenda, which will overtax a significant proportion of the students.

In current Anglo-American countries, the educational decisions made during childhood are less drastic, although here too the path has been forged ahead. The subjects chosen in high school as well as the learning outcomes in these subjects have a strong impact on performance in college entrance tests (Allensworth & Clark, 2020). Both systems have pros and cons which will not be discussed here in detail, as there is no silver bullet available on how to deal with the diversity in intelligence. However, there is a justified concern in all systems that, in cases of doubt, social background determines the educational path more than intelligence. The golden age of social mobility through education has come to an end (Goldthorpe, 2016), which makes access to university education more difficult for intelligent children from non-academic families, while parents with academic background likely find ways to navigate their children through the educational system widely independent of their cognitive preconditions (Blossfeld et al., 2016). Neglecting the role of intelligence in educational and professional careers not only contradicts the ideals of a meritocratic society, but is also likely to lead to a discrepancy between supply and demand for professional qualifications – with consequences for the functioning of a society. For many – but not all – content areas and career tracks, less intelligence can be compensated for by investing more effort into acquiring the necessary knowledge.

4.2 Beyond mere intelligence scores – roots of cognitive differences

From studies with identical and fraternal twins, it is uncontested that genetic differences can explain a considerable amount of variance in IQ. The correlation between test scores of identical twins raised together approaches $r = .80$ and thereby is almost equal to the reliability coefficient of the respective test. On the other hand, IQ-correlations between raised-together same-sex fraternal twins are rarely higher than .50, a value also found for regular siblings (Stern, 2017). Given that the shared environment for regular siblings is lower than for fraternal twins, this result qualifies the impact of environmental factors on intelligence. A still widespread misunderstanding is to equate "genetic sources" with "inevitability" because people fail to recognize the existence of reaction norms, a concept invented in 1909 by the German biologist, Richard Woltereck. Reaction norms depict the range of phenotypes a genotype can produce depending on the environment (Woltereck, 1909). The environment regulates gene expression, which means that instead of "nature versus nurture", a more accurate phrase is "nature via nurture" (Ridley, 2003).

The complex interaction between genes and environment can also explain the fact that heritability of intelligence increases during the lifespan (Deary, 2004). This well-established finding is a result of societies in which a broad variety of cognitive activities available in professional and private life enable adults more than children to actively select special environments that fit their genes. People who have found their niche can perfect their competencies by deliberate learning. The amount of variance in intelligence test scores explained by genes is higher the more society members have access to school education, health care, and sufficient nutrition. There is strong evidence for a decrease in the heritability of intelligence for children from families with lower socioeconomic status (SES). For example, lower SES fraternal twins resembled each other more than higher SES ones, indicating a stronger impact of shared environment under the former condition (Tucker-Drob & Bates, 2016). In other words, because of the less stimulating environment in lower SES families, the expression of genes involved in the development of intelligence is likely to be hampered. Although it may be counterintuitive at first, this suggests that a high heritability rate of intelligence in a society is an indicator of economic and educational equity. Additionally, this means that countries that ensure access to nutrition, health care and high-quality education independent of social background enable their members to develop their intelligence according to their genetic potential. This was confirmed by a meta-analysis on interactions between socioeconomic status and heritability rate. While studies run in the United States showed a positive correlation between socioeconomic status and heritability rate, studies from Western Europe countries and Australia with a higher degree of economic and social equality did not (Turkheimer et al., 2003).

4.3 Working memory functions as the source of individual differences

Thanks to the numerous studies on intelligence, we now have a deeper insight into the structure of cognitive abilities. Among the most frequently replicated results is the so-called positive manifold, which means the significant positive correlations between all kinds of subtests measuring reasoning and efficiency of information processing, no matter whether a verbal, numerical or visual format is used. The shared variance is labelled general intelligence or factor g (Stern, 2017). The interpretation of factor g is still under discussion, and the most promising candidate for factor g is the well-established concept of working memory, which is understood as a mental workspace that is responsible for maintaining incoming information and combining it with already existing knowledge for efficiently approaching a goal (Shipstead et al., 2016). Working memory functions are measured by speed tasks that require goal-oriented active monitoring of incoming information or reactions under interfering and distracting conditions. The success of learning environments such as those provided at school depends on the extent to which they manage to use working memory functions efficiently. This concerns three aspects to be discussed in the following.

First, the efficient construction of knowledge allows to better exploit working memory functions. This has been intensively discussed in section 2 of this paper. If chunked knowledge patterns, automated actions and well-structured conceptual networks can be retrieved from long-term memory, incoming information can be efficiently processed and thereby support further learning. Differences in working memory functions and in reasoning ability can be compensated by well-established prior knowledge in many content areas (Stern, 2017). In other words, learners who do not score at the upper end in cognitive preconditions can acquire a solid level of competence by investing time into efficient knowledge construction. At the same time, we have to acknowledge limits in compensating for less efficient cognitive functioning in terms of working memory and reasoning abilities. More intelligent learners better exploit learning opportunities and achieve higher as long as there is no ceiling effect in the outcome measures (Peteranderl et al., 2023). Also, the complexity of content areas and the abstractness of the concepts in these content areas regulates the requirements placed on intelligence (Berkowitz et al., 2022). University education that deserves its name should place high demands on intelligence.

Secondly, learning environments and learning material should allow to focus on the content and avoid distraction – or extraneous load – as it is formulated in the well-established cognitive load theory from Sweller (2010). Enabling learners to invest their working memory capacity into the content is a core competence of teachers and educational developers. This also includes to make use of the so-called germane load, which implies support learners in acquiring demanding abstract concepts by facing them with challenging learning environments. A research area labelled as "Desirable Difficulties" is evaluating means of instruction which are supposed to prevent learners from jumping to conclusions and making unjustified simplifications.

The third point refers to the development of working memory functions and reasoning ability. People are born very immature, and this is especially true for frontal brain areas that guide working memory functions. Supported by brain imaging techniques as well as by behavioral observation, it is well known that until the age around 3–4, children are completely overwhelmed with simple tasks that require a change of goals. Working memory functions (sometimes labeled as executive functions) improve in the following years steadily and reach their individual maximum only in early adulthood. Particularly during the period of adolescence, youngsters often react when regarding challenged by problems that require the careful planning of actions. Learning environments developed for children and adolescents should take into account that during this age period learners are particularly prone to being distracted and have difficulties with properly structuring actions in complex situations (Steinberg, 2017). Supporting learners in developing planning strategies, for example by giving cues may help them to better exploit learning environments.

5. Perspectives for empirical educational research and implications for practice

In the past decades, considerable progress has been made in better understanding how the human mind works and how motivation can be maintained. Developmental constraints during childhood and early adolescence are now quite well understood, and that also goes for individual differences within age groups. I see two major lines of promising as well as necessary research: 1. Monitoring the role of intelligence in career trajectories as well as attempts to mitigate the dominance of social background; 2. Considering the impact of working memory functions for learning.

Ad 1: On the one hand, we have to do justice to the fact that all people have learning potential and have the right to master competencies necessary for participating in modern societies. On the other hand, for individual and societal benefit, those with above average cognitive competencies should get the opportunity to unfold them from the very beginning. Alternatives to the currently existing tracking systems, which do not do justice to continuous distribution of intelligence, are urgently needed. By developing learning environments and materials that are better adapted to human working memory functions as well as to the differences in these functions may mitigate the challenges in managing diversity. The development and the evaluation of adaptive digital learning tools should be prioritized.

Changing school systems is a long and tedious process, and in Germany several attempts to overcome the disadvantages of tracking were doomed to failure. Future changes need to be better planned. In the meantime, to mitigate the impact of social background on admission to university education, educational sciences should carefully evaluate under what conditions intelligence tests can help to make decisions as fair as possible.

Ad 2: The central role of working memory functions in academic learning from a universal, a developmental, and a differential perspective should determine further research. Thanks to the cognitive load theory, the universal perspective is ready to be implemented in learning material and environments. More research, however, is needed concerning constraints in brain development affecting working memory functions. While early childhood and adolescence got sufficient attention, more has to be learned about the affordances and constraints of working memory among elementary school children in order to optimally exploit their learnability in the first years of school, when the foundations for literacy as well as for mathematical and scientific reasoning are laid.

As discussed above, working memory and reasoning abilities measured in intelligence tests are closely related, but they are not identical. Reasoning abilities need cognitive challenges to develop, facilitated by a well-functioning working memory. While measures of reasoning and working memory show high correlations, there are deviations in both directions. Some individuals with high working memory functions do not fully translate these into reasoning. Others are able to develop reasoning abilities that exceed their working memory functions. Future research should focus on reasons for these patterns as well as consequences for future learning.

Regarding the implications for practice, the fruitful collaboration between learning scientists and subject-specific experts should be continued. Teacher education programs as well as training programs for in-service-teachers should focus on the implementation of proven means for useful knowledge construction in core content areas of their subject. Awareness for the mission of formative assessment and implementing it into daily classroom practice should be a top priority. Understanding what exactly causes students' difficulties can then help to offer the appropriate learning opportunities.

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