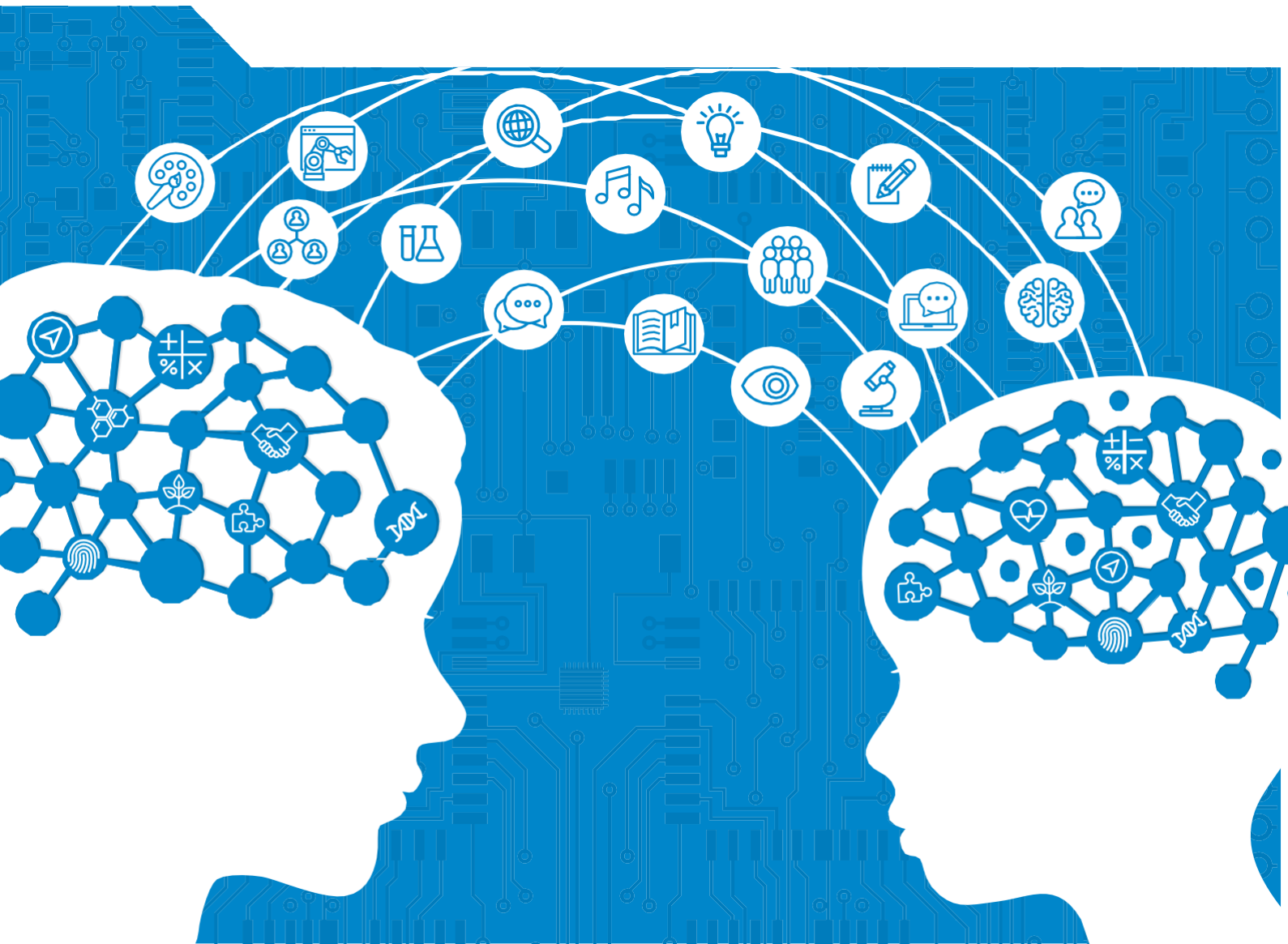


Educational Research and Innovation

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TOWARDS A SCIENCE OF LEARNING FOR
21ST CENTURY EDUCATION

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Chapter 5. The role of anxiety and motivation in students' maths and science achievement

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Ensuring that all students can perform up to their potential in school is a central goal in education. As such, improving students' ability and skill is often the main focus of educational interventions. However, psychological factors such as anxiety and motivation are also important for student learning and success. Those students with high levels of anxiety and low levels of motivation tend to perform below their capabilities – even when they have high levels of skill and ability. We review recent work showing the importance of parents and teachers in shaping students' attitudes, interest and persistence in maths and science. We also highlight classroom and home interventions shown to be effective in combating high levels of student anxiety and low levels of student motivation and reducing the harmful learning consequences of negative affect.

There is no doubt that students' ability and knowledge are important predictors of their advancement in school and beyond. However, it is also the case that students' attitudes and beliefs about school play a large part in their academic success. In this chapter, we focus on recent research around the world demonstrating the important role of academic attitudes (specifically anxiety about performing at a high level and motivation to exert effort in order to learn) in academic achievement. First, we define key attitudes that are implicated in students' academic performance. Second, we discuss the growing evidence about the influence of caregivers in the development of students' academic attitudes. Third, we review emerging research on interventions to improve academic achievement by changing students' anxiety and motivation as well as the attitudes of the adults who interact with students. This research demonstrates that efficacious low-cost and light touch interventions are available to put into educational practice to help students learn and achieve. Finally, we point to future directions for research in this area.

Performance anxiety

Imagine two middle school students, Jason and Tracy, who have equivalent maths knowledge and are about to take a test on algebra. Jason always gets anxious when doing maths, and as he begins the test, he starts thinking negative thoughts (e.g. "I can't do this! I'm just not a maths person") and his heart starts racing. The worries he experiences make it hard for him to concentrate while calculating answers to the maths problems. Tracy, on the other hand, is not anxious about maths at all and experiences none of these anxious responses. Thus, she can more easily concentrate on the maths problems and receives a higher test score.

Performance anxiety is defined as the worries and fears students have about performing well on a certain task or in a certain domain (Beilock, Schaeffer and Rozek, 2017_[1]). Maths anxiety, or fears and apprehension about doing maths, is the most highly researched subject-specific type of performance anxiety in school, so we focus our discussion on that topic, even though students can suffer from performance anxiety in other subjects as well (e.g. anxiety about reading or about taking tests generally). Maths anxiety can be expressed as negative thoughts and emotions about doing maths as well as increased physiological arousal, which can include an elevated heart rate, dry mouth and sweaty palms (Dowker, Sarkar and Looi, 2016_[2]).

Maths anxiety has been consistently shown to be associated with worse maths performance for students (Dowker, Sarkar and Looi, 2016_[2]). Recent findings from international assessments of adolescents' support that this is truly a global phenomenon (Foley et al., 2017_[3]). In a report on data from the Programme for International Student Assessment (PISA), high maths anxious students performed worse than low maths anxious students in 63 out of the 64 countries examined. Not only was that the case, but countries with higher levels of maths anxiety (high maths anxious countries) tended to perform more poorly than countries with lower levels of maths anxiety. This effect was reliable for high ability, middle ability and low ability students and was even descriptively stronger for high ability students. Other studies, mainly carried out in the United States, show that maths anxiety arises early in development – by first grade, students who report feeling anxious about maths perform worse at maths (Ramirez et al., 2016_[4]). These findings are concerning, given that more than 50% of people suffer from some level of maths anxiety by adulthood (Dowker, Sarkar and Looi, 2016_[2]).

Why does maths anxiety undermine students' academic achievement? Although various types of performance anxiety are topic-specific (e.g. maths anxiety) or task-specific

(e.g. test anxiety), all types of performance anxiety are theorised to work through similar mechanisms (Beilock, Schaeffer and Rozek, 2017_[1]). In particular, working memory, or our limited capacity system used for temporarily storing information, is implicated in the deleterious effects of performance anxiety (Beilock, Schaeffer and Rozek, 2017_[1]). Individuals differ in their natural working memory capacities, with some having higher working memory (HWM) capacities and others having relatively lower working memory (LWM) capacities. Students with higher levels of working memory tend to do better on academic tasks, likely because they can store information to use while doing, for example, different parts of a maths problem. Counterintuitively, individuals with higher levels of working memory have been shown to be most hurt by performance anxiety (Beilock, Schaeffer and Rozek, 2017_[1]; Ramirez et al., 2016_[4]). For example, those students would otherwise be able to use highly efficient problem-solving strategies that make use of their HWM, but maths anxiety reduces the availability of cognitive resources, leading to underperformance compared to HWM students who are low in maths anxiety (Ramirez et al., 2016_[4]).

Recent neuroscientific work has also shed light on the mechanisms underlying the effects of maths anxiety on maths performance. In the first study on the neural basis of maths anxiety, 7- to 9-year-old children were asked to complete maths tasks while having their brains scanned in a magnetic resonance imaging (MRI) machine (Young, Wu and Menon, 2012_[5]), allowing researchers to see which parts of the brain are being used during the task. Results showed that higher maths anxious children, as compared to lower maths anxious children, had increased activation in areas of the brain related to negative emotions as well as those involved in controlling negative emotions (i.e. hyperactivity in right amygdala and increased connectivity between the amygdala and the ventromedial prefrontal cortex). This pattern of activation suggests that high maths anxious children had to expend mental effort to regulate their anxiety. Other brain imaging studies on adults have supported these findings by showing that even anticipating doing maths activates threat and pain areas of the brain (Lyons and Beilock, 2012_[6]).

Motivation

In addition to performance anxiety (and specifically as outlined above regarding maths anxiety), students' motivation to perform well is implicated in maths and science achievement. Consider two high school students: Myeshia and Kenny. Myeshia is very confident in her maths ability. She also views maths as important to her future because she plans to become an engineer, which requires a strong maths background. Thus, she enrolls in all of her high school's advanced and optional maths courses, including statistics and calculus. Kenny, on the other hand, is also confident about his maths ability, but he is always asking his maths teachers, "When will I ever use this in real life?" Because he does not see the value of maths, he decides to take additional elective language classes instead of optional maths courses. Inevitably, when taking college entrance exams, Kenny scores lower on the maths section than Myeshia because he was exposed to less maths during high school.

Although there are a variety of theories of motivation relevant to educational achievement, here we focus on expectancy-value theory. Eccles and colleagues have proposed that students' achievement and achievement-related choices, such as being engaged in school and enrolling in elective maths classes, are the result of their expectations to succeed in a particular domain (can I do this?) and how much they value a certain domain (why do I care about this?) (Eccles and Wigfield, 2002_[7]). Based on the above examples, it is easy to

see how students need to expect to succeed in a topic and to value a topic to be optimally motivated. Both Myeshia and Kenny had high expectations for success in maths, but only Myeshia highly valued maths. This difference in their motivational attitudes led to different choices and to differential maths learning.

Decades of correlational research supports this finding: Both students' expectations for success and how much they value a subject contribute to their academic performance and choices, such as course-taking (Eccles and Wigfield, 2002^[7]). These effects appear to replicate internationally with studies on adolescents. Using PISA data from nearly 400 000 students across 57 countries, researchers showed that students' expectations and values in science were associated with a variety of student outcomes, including participation in science-related extracurricular activities and science career pursuit (Nagengast et al., 2011^[8]). This pattern of results largely generalised across the various countries in the study. Higher expectations and value promote optimal performance in school through a variety of mechanisms, especially through students' choices to invest in increased effort, engagement and persistence on school-related tasks, such as persisting longer during maths activities like homework and studying (Durik et al., 2015^[9]) or choosing to enrol in optional maths courses in high school (Rozek et al., 2017^[10]).

The role of teachers and parents in students' attitudes and performance

Having established that individuals' maths and science attitudes can affect their performance, we next ask how these attitudes develop. It turns out that the attitudes of caregivers can influence the attitudes and performance of students. Specifically, teachers' and parents' anxiety and motivational attitudes are associated with students' attitudes and performance.

Teachers

One study of first and second grade teachers investigated whether teachers' maths anxiety was associated with students' attitudes about maths and their maths learning during the school year (Beilock et al., 2010^[11]). Results showed that students of maths anxious teachers learned less maths over the course of the school year; however, this finding was only significant for female students. Given that gender is salient even at early ages and elementary school teachers are overwhelmingly female, female students might be more likely to pick up on their teachers' negative attitudes about maths and look to them as role models (Dasgupta, 2011^[12]). Female students also developed negative stereotypes about females and maths when they had a maths anxious teacher, which other research has shown is harmful for their attitudes about maths (Cvencek, Meltzoff and Greenwald, 2011^[13]). Finally, the analyses suggested that young girls were underperforming in classrooms with maths anxious teachers due to their increased negative attitudes about maths that developed over the school year, suggesting that teachers' attitudes about maths might affect students' maths performance by changing their attitudes about maths.

In addition to teachers' maths anxiety, several studies have shown that teachers' expectations about their students' success in class are associated with their students' own expectations for their success as well as their performance in class. In two studies of elementary school students, teachers' expectations for each student were associated with students' future performance, even after controlling for students' prior performance (Friedrich et al., 2015^[14]; Upadyaya and Eccles, 2015^[15]). Furthermore, the association between teachers' expectations and students' achievement was partially accounted for by the association between teachers' and students' expectations for success. That is, when

teachers viewed a student as more likely to succeed in class, that student viewed himself or herself as more likely to succeed in class, and because of that, students performed better in class.

Parents

Research also supports the role of parents' attitudes in students' academic achievement. Parents' maths anxiety has been shown to be negatively associated with elementary school students' maths learning (Berkowitz et al., 2015_[16]; Maloney et al., 2015_[17]), such that students learn less maths if their parents are more highly maths anxious. This lower performance, might in turn, contribute to students' maths anxiety (Gunderson et al., 2018_[18]). Further, parents' maths anxiety may directly lead to students' maths anxiety (Soni and Kumari, 2015_[19]), which may undermine children's maths achievement.

Parents' expectations for their children in school and how much they value maths and science for their children have both been shown to be associated with student attitudes and outcomes (Jacobs and Eccles, 2000_[20]). Parents' expectations seem to act as a filter through which children understand their abilities, such that the feedback that children receive in school (e.g. grades) affects their expectations for success to the extent that the feedback affects their parents' expectations for their success in school. This is because children look to their parents to interpret the meaning of feedback (Jacobs and Eccles, 2000_[20]). Likewise, parents who value maths and science for their children tend to have children who value these domains and enrol in additional relevant courses in high school (Svoboda et al., 2016_[21]).

Interventions to reduce performance anxiety and increase motivation

Recent research in psychology has focused on improving students' performance by reducing negative attitudes or promoting their positive attitudes about learning. Often, these interventions involve activities that students complete in school to change their attitudes about learning in beneficial ways. Though many interventions are student-centred, other interventions focus on parents to help improve students' attitudes and performance.

Student-centred attitude interventions

Targeting students' attitudes with interventions in the classroom has shown much promise as one route to improving students' performance in school. Performance anxiety interventions typically involve students expressing, re-evaluating and/or normalising their worries. Motivational interventions focus on raising students' expectations for success or increasing their perceived value of a subject, such as maths.

One type of performance anxiety intervention, expressive writing, involves having students write about their anxiety before taking a test in order to offload their worries. By doing this, it is thought that students can free up their cognitive resources to use on the test, which would otherwise be consumed by their worries. Indeed, this kind of intervention has been found to improve maths problem-solving performance for maths anxious individuals (Park, Ramirez and Beilock, 2014_[22]) and final exam performance for high school biology students (Ramirez and Beilock, 2011_[23]).

A second type of performance anxiety intervention focuses on helping students reappraise or normalise their performance anxiety. Reappraisal interventions improve performance by teaching students that the anxious arousal (e.g. fast heart rate) they feel during a test is actually beneficial (e.g. because it means more blood flow and energy in the brain).

Jamieson and colleagues (Jamieson et al., 2016_[24]) found that giving community college maths students this information directly before a test improved their exam scores and helped them feel more capable of performing well in the class. Another study found that normalising performance anxiety improved women's performance in college engineering classes and helped them feel more capable of academic success and managing stress in school (Walton et al., 2015_[25]), a finding that replicates across several age groups. Interventions that normalise performance anxiety involve teaching students that encountering difficulty in school, on a particular task or in a particular class is an experience common to many students, which helps them attribute low performance to temporary causes (e.g. this happens to everyone at first) instead of unchangeable low ability (e.g. this just happens to me because I am stupid).

A frequently used motivational intervention aims to change students' expectations by teaching them a growth mind-set, which is the idea that their intelligence is malleable and can grow (as opposed to being fixed). Believing that intelligence can grow and change helps students persevere through difficulty and is associated with many positive self-beliefs, which is a finding that replicates in international settings (Claro, Paunesku and Dweck, 2016_[26]). In one study, Blackwell and colleagues (Blackwell, Trzesniewski and Dweck, 2007_[27]) found that middle school maths students given a growth mind-set intervention, as compared to students in a control group, showed improved motivation and higher grades.

A second type of motivational intervention is used to increase students' value in a topic. These relevance interventions involve asking students to write brief essays to explore the utility of what they are learning by making connections between the material and their lives. In a study of high school students in science courses, results showed that the relevance intervention was particularly effective for students who lacked confidence in their ability to perform well in the class – exactly the students who needed a boost (Hulleman and Harackiewicz, 2009_[28]). Students in the relevance condition who lacked confidence in their abilities reported valuing science more and performed nearly three-quarters of a grade point better in terms of their course grade than low confidence control group students. These findings show that relevance interventions hold promise for improving students' attitudes and performance in class.

Parent-centred attitude interventions

The interventions described in the previous section were all directed at students. Another type of intervention focuses on improving students' attitudes and performance by engaging their parents. For example, one parent-centred intervention focused on reversing the negative effects of parents' anxiety on their children's performance (Berkowitz et al., 2015_[16]). In this study, intervention group parents were asked to use a maths intervention, delivered via an electronic app on tablet devices, with their children that was designed to provide structured, fun parent-child maths interactions. Control group parents were asked to use a reading app with their children, similar to what many parents already do with their children. Results showed that in the control group, children of maths anxious parents learned less maths during first grade, consistent with prior findings (Maloney et al., 2015_[17]). In contrast, in the intervention group, children of maths anxious parents learned as much maths during first grade as children of less maths anxious parents. Thus, providing a way to support positive parent-child maths interactions eliminated the negative relation between parents' maths anxiety and children's maths learning.

Similar benefits have been shown with interventions that target parents' motivational attitudes. In one study, parents of second grade students in Denmark in an intervention group were taught about having a growth mind-set for their children's intelligence (i.e. that their children's intelligence can grow with effort; (Andersen and Nielsen, 2016_[29])). Compared to children of parents in the control group, children of parents in the intervention group showed greater improvement in their academic achievement over the school year. In another study, parents of high school students were either assigned to an intervention group that asked them to talk about the relevance of maths and science with their children or a business-as-usual control group (Rozek et al., 2017_[10]). The intervention increased the value parents placed on maths and science for their children. Moreover, children of intervention group parents benefitted – they enrolled in more maths and science courses in high school, performed 12-percentile points better on their maths and science subsections of their college entrance exams and reported improved motivational attitudes about maths and science.

Future directions

Although the current state of knowledge has allowed for many important advances, future research is still needed in many areas. Here, we discuss four promising future directions. First, more studies are needed to understand how anxiety and motivational interventions may need to differ to be developmentally appropriate for students of different ages and cultural backgrounds. To date, many interventions have focused on students who already exhibit performance anxiety or are beginning to show declines in motivation rather than on preventing anxiety from arising in the first place or maintaining the higher levels of motivation seen for students in elementary school. Further, current instantiations of some of the interventions that have been studied with middle school and high school students may not work with very young students. For example, expressive writing interventions with adolescents typically involve a reading and writing activity. However, with elementary school students, it might be more feasible to ask students to talk about their worries or to create drawings about their worries instead, given age-related differences in students' abilities to express themselves in writing.

Second, although some interventions are beginning to incorporate technology (Berkowitz et al., 2015_[16]; Paunesku et al., 2015_[30]; Rozek et al., 2017_[10]), it will be advantageous to utilise technology in the development of anxiety and motivation interventions. Technology can help make learning exciting (e.g. more game-like), which could be appealing and motivating for children. Computer adaptive technology also allows for greater customisation for scaffolding to children's specific abilities, which could help with providing more personalised support for each student.

Third, the majority of the anxiety and motivation intervention research focuses on student-centred interventions. However, given the large role that caregivers play in the development of children's academic attitudes, it is important to consider caregiver-focused interventions as well. Parents, in particular, are a relatively untapped resource and can be engaged to help students perform up to their potential in school. Although research is just beginning on parent attitude interventions, three recent studies (Andersen and Nielsen, 2016_[29]; Berkowitz et al., 2015_[16]; Rozek et al., 2017_[10]), suggest that parents can improve their children's performance in school with the help of interventions that change parents' attitudes and the ways they interact with their children. Natural advantages of parent-centred interventions include that students spend more time at home than they do in school, and students keep their parents year after year, as compared to teachers who typically

change each year. Given the great potential of parent-focused efforts to improve children's achievement, research should continue to explore the myriad ways that parents can support their children's learning.

Finally, researchers should develop interventions for teachers in order to positively impact their students (e.g. reducing teachers' maths anxiety to help improve their students' maths achievement). The research on parent interventions provides a starting point for thinking about how to create supports for teachers, but teachers work with many students and have different relationships with them than parents, which might require different types of interventions than what is used with parents. Although it might be complicated, intervening to change teachers' attitudes is another promising avenue for improving students' attitudes and performance.

Of course, as described in the intervention section, it is possible to deploy interventions that target students themselves as well as their teachers and parents. A co-ordinated effort that focuses on intervening at all levels (i.e. parents, teachers and students) may lead to the greatest positive impacts on student learning outcomes.

Policy implications

Ensuring that all students can perform up to their potential in school is a central goal in education. As such, improving students' ability and skill is often the main focus of educational interventions and policy. However, psychological factors, such as anxiety and motivation, are also important for student learning and success. Those students with high levels of anxiety and low levels of motivation tend to perform below their capabilities – even when they have high levels of skill and ability. In response to these findings, researchers have developed an emerging group of low-cost and light touch home and classroom interventions to promote student learning by decreasing anxiety and improving motivation for students. Policymakers could make use of this research in two main ways. First, schools may benefit from assessing students' anxiety and motivation in addition to academic performance in order to identify when students across the ability spectrum might be suffering from high anxiety or low motivation. Second, policymakers should work with researchers to integrate anxiety and motivation interventions and supports into students' classrooms and home environments in order to enhance student achievement in mathematics, science and other domains.

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