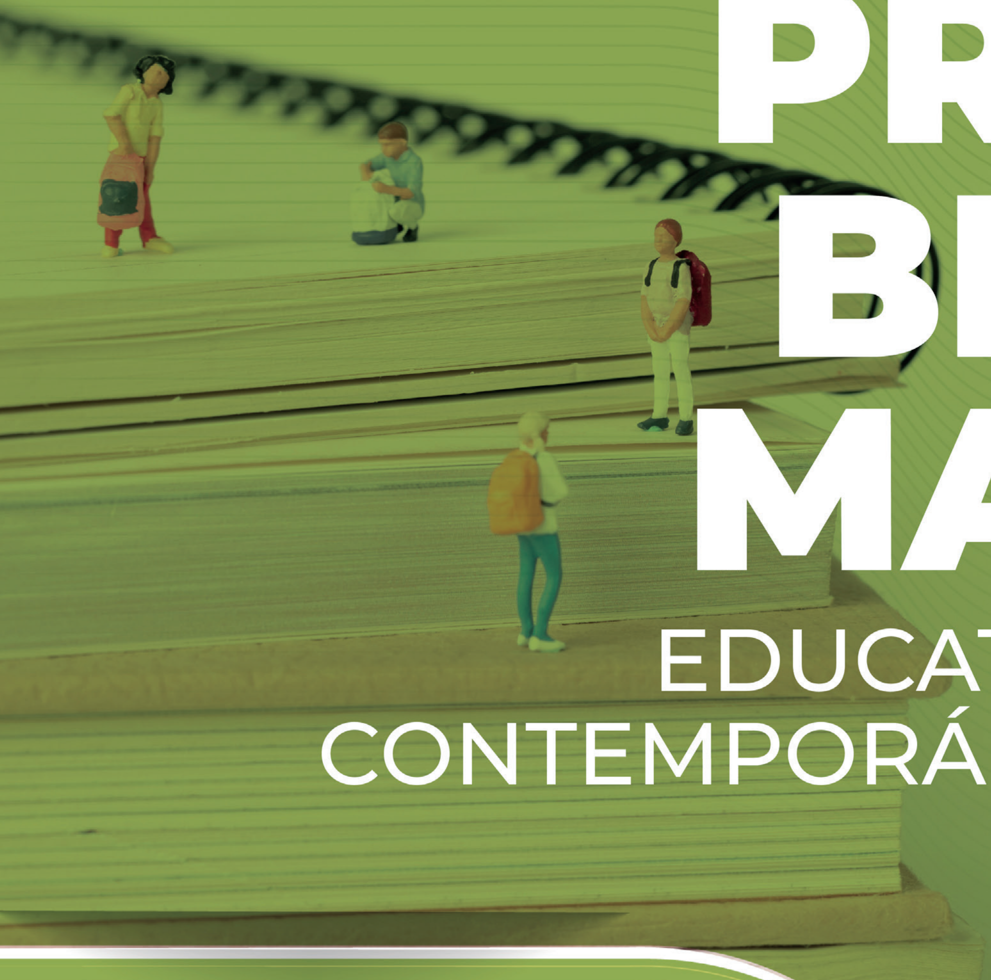
RESPUESTAS A PROBLEMAS EDUCATIVOS CONTEMPORÁNEOS



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CAPÍTULO I

INTERVENCIÓN PSICOSOCIOEDUCATIVA

1.1. Executive Functions and Classroom Behavior and Achievement

Funciones ejecutivas, comportamiento en el aula y logros académicos

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Abstract:

Executive functioning, or the high-level, top-down control of processes, is a concept that originated in computer science, but has since been extensively applied within psychology, pedagogy, and cognitive science to understand intelligent behavior. Furthermore, damage to the frontal lobes of the brain frequently produces a breakdown of executive control, and such patients often fail in education, training, and employment, despite normal intelligence. This suggests a special role for executive functions in real-life achievement. Findings such as these have motivated researchers from diverse disciplines to development a new discipline-educational neuroscience. As an example, I review how research on executive functions and the brain can help us to understand both misbehavior in the classroom, and academic achievement, drawing particularly on research conducted in Latin America. This research indicates an important role for response inhibition in academic achievement, and working memory in classroom behavior. Importantly, executive functions such as these can be improved to enhance educational performance and well-being. Lifesyle changes can improve brain health, and education has a powerful role in improving neurocognitive functions.

Keywords: academic achievement, cognitive control, dysexecutive syndrome, neuroeducation, student misbehavior

Resumen:

El funcionamiento ejecutivo, o control descendente de alto nivel de los procesos, es un concepto que se originó en las ciencias informáticas, pero que desde entonces se ha aplicado ampliamente en la psicología, la pedagogía y la ciencia cognitiva para comprender el comportamiento inteligente. Además, debido a que, los daños en los lóbulos frontales del cerebro producen con frecuencia un colapso del control ejecutivo, estos pacientes suelen tener un mal rendimiento en la educación formal, la formación y el empleo, a pesar de tener una inteligencia normal. Esto sugiere un papel especial de las funciones ejecutivas en los logros de la vida real. Hallazgos como estos han motivado a investigadores de diversas disciplinas a desarrollar una nueva disciplina: la neurociencia educativa. A modo de ejemplo, este artículo repasa cómo la investigación sobre las funciones ejecutivas y el cerebro puede ayudarnos a entender tanto el mal comportamiento en el aula como el rendimiento académico, basándome especialmente en investigaciones realizadas en América Latina. Esta investigación indica un papel importante de la inhibición de la respuesta en el rendimiento académico y de la memoria de trabajo en el comportamiento en el aula. Es importante destacar que estas funciones ejecutivas pueden mejorarse para aumentar el rendimiento educativo y el bienestar. Los cambios en el estilo de vida pueden mejorar la salud del cerebro, y la educación tiene un papel fundamental en la mejora de las funciones neurocognitivas.

Palabras clave: rendimiento académico, control cognitivo, síndrome disejecutivo, neuroeducación, mal comportamiento del alumno

1 Introduction

There is a growing understanding that pedagogy can benefit substantially by incorporating knowledge from brain and cognitive sciences. These latter fields have made substantial gains in recent years in understanding human learning, reading ability, attention, behavior regulation etc., in both neurotypical and neurodivergent development (e.g., autism, attention-deficit hyperactivity disorder).

While clinical neurosciences have revealed much about how the brain organizes behavior in health and disorder, particularly involving the frontal lobes of the brain (e.g., Lee et al., 2015; Pluck & Lee, 2013), cognitive sciences have used a computational metaphor to elucidate the information processing that underlies human intelligent goal-directed behavior through cognitive abilities, such as attention, working memory and language use (e.g., Cerone et al., 2022; Cerone & Pluck, 2021).

At the same time, cognitive and neuroscientists have sought to extend their work to ecologically valid contexts and to assess their theories practically, such as in educational institutions. Brain and cognitive sciences can benefit substantially by incorporating grassroots knowledge from teachers and advancements in educational studies. Thus, knowledge and understanding from the practice and scholarship of learning and teaching can inform basic understanding of brain and behavior in real-life.

This symbiotic relationship has led to the development of a new discipline, *educational neuroscience*, also sometimes referred to as *neuroeducation*. Furthermore, greater awareness has developed of the intertwined benefits of education and cognitive function on multiple aspects of health and wellbeing. Central to this has been the concept of *executive functions*. These are proposed as high-level cognitive processes, involving the prefrontal regions of the brain, that control lower-level processes to allow flexible, intelligent, goal-directed behavior (Pluck & Cerone, 2023; Pluck, Crespo-Andrade, et al., 2020). These abilities require attention, and mental effort, usually to overcome some habitual response.

In neuroscientific literature, the term *cognitive control* is often used instead. Whichever expression is used, it refers to skills such as holding information in consciousness while using it to perform tasks (working memory), preventing oneself from performing actions (inhibition), and efficiently changing the way that tasks are performed (switching). Although many other abilities can be described as 'executive' there is a broad consensus that the three core executive functions are as described above: working memory, inhibition, and switching. Other processes also considered to be executive in nature are: planning, reasoning, seeing past concrete appearances to appreciate abstract relations between concepts, producing random ideas, sequentially producing responses from very large sets (e.g., saying words beginning with 'P'), and estimating unknown quantities (e.g., the number of camels in the Netherlands).

One can immediately see how these executive functions contribute to how people organize intelligent behavior. The concept has proven very useful in a range of fields. In psychiatry it has been noted that most (perhaps all) psychiatric illnesses involve some aspects of failing executive function. As an example, patients with schizophrenia who have relative difficulty with response inhibition are at increased risk of committing acts of self-harm (Lee et al., 2015). Similarly, in organizational psychology, it has been observed that relatively better response inhibition predicts better workplace performance of sales personnel (Pluck, Crespo-Andrade, *et al.*, 2020). Given the explanatory power of executive functions, there is great interest in not only understanding how they predict educational performance, but how they can be improved to help individuals achieve more, to be healthier, to have greater feeling of wellbeing, and to thrive in general. Nevertheless, many educationalists, psychologists and neuroscientists have a limited understanding of what executive cognitive processes are, and their potential for improvement. These issues are explicated in the following sections.

Executive functions

The concept of executive functions originated in computer science in the 1950's. At the time, it was realized that top-down control of computer programs was needed, meaning that a master program could decide which programs to run, and when to stop them and start the next program etc. The first of these, called the *Automatic Supervisor*, was implemented in 1956, and other companies soon followed suite developing similar master programs with names such as *Executive System*, *Executive Monitor*, and *Supervisory Control Program* (Pluck & Cerone, 2023). Also in 1956, a small conference took place in which computer scientists, linguists, neuroscientists, and psychologists came together to discuss how minds could be investigated in terms of information processing. The new field that developed from this meeting, *cognitive science*, took computational concepts and terminology and applied them to the human mind. As executive controls were at the time so important in computer science and programming, the concept was readily taken up by cognitive scientists interested in the human mind.

Over the following years two import theories of this kind developed. Baddeley and Hitch (1974) published their Working Memory Model (including a *Central Executive subsystem*) and

Norman and Shallice (1980) published their model of willed and automatic behavior (including a *Supervisory Attentional System*). Note that the same terminology as used in computer science was adopted. Although they are often discussed as separate theories, the executive component of both theories is the same. The Working Memory Model differs only in that it focuses on executive control of memory stores, including a visuospatial store and a phonological store- equivalent to what is commonly referred to as Short Term Memory (Cerone *et al*., 2022). Thus, the executive concept from computer science became an important topic in cognitive sciences, to explain how people control non-routine behavior.

From the cognitive perspective, and drawing on studies of instrumental conditioning, executive functions can be formalized as processes in the mind that are performed to help a person achieve a goal. A defining characteristic is therefore that they are *goal-directed*. It may seem obvious that actions are goal-directed, but in fact much of what we do is not. Processing in the brain, to find ways to achieve our goals requires analysis of multiple sub-goals. This is computationally and physiologically expensive endeavor (discussed in Section 3.1). Instead, we develop habits, known in cognitive science as procedural learning, in which we can act without much executive (self-)supervision. The classic example is driving a car. Most experienced drivers are able to perform this very complex and skilled behavior without much attention. This is explained, for example, with Norman and Shallice (1980)'s model, in which routine, automatic actions such as changing gear, breaking when the car in front does, indicating to make a turn, even making phone calls etc. are controlled by a habit-based system. It is only when something unusual or imminently dangerous happens, such as steam billowing from under the car's hood, that the Supervisory system becomes fully active to plan what to do in this unanticipated situation.

Around the same time as concepts of executive function entered cognitive psychology, from computer science, the neuroscientist Karl H. Pribram (1973) suggested that the frontal lobes of the brain may run *executive programs*. This was consistent with a long history of observations from clinical neurology, that damage to the frontal lobes often resulted in behavior that was disorganized, inefficient, lacked planning, and was disinhibited. Patients can be rude, insensitive, easily angered, reckless, and lack prudence. That pattern became known as the *dysexecutive syndrome*. The patients seem to have symptoms that would be expected if they had reduced ability for executive control of their behavior. Importantly, many cases were described in the clinical neurology literature of patients who developed this syndrome, but appeared to have normal IQ scores. Despite their apparent intelligence, many failed to maintain employment or dropped out of education and training programs. For detailed description of such cases see Pluck, Crespo-Andrade, *et al*. (2020) and Pluck and Cerone (2023).

The real-life failures of people with the dysexecutive syndrome suggested that executive processes of the human mind may have some special link to achievement, such as success in education, going beyond that already associated with intelligence. In fact, this is what has been found, executive functions may be more important than psychometrically measured intelligence in understanding educational progress. This issue is discussed in the following section.

Executive functions and academic achievement

The Working Memory Model (Baddeley & Hitch, 1974) was originally developed to explain results from psychology experiments. However, the biological reason for the overall working memory system was unknown. This was elucidated when research applying working memory procedures revealed a close link to language use and language learning. Healthy people with good phonological working memory ability, compared to those with poor ability, have much better comprehension of verbal materials. Furthermore, patients with brain damage that impairs working memory are very, very poor at learning vocabulary. This led to theorization, and computational models (Cerone *et al*., 2022), that the phonological part of working memory is a language processing and learning device.

As children (and adults) show a wide range of ability, we might expect that those with the best executive- working memory ability would be able to learn languages more easily. This is exactly what has been found. Better working memory predicts language grades of school children. A study in Ecuador of high school adolescents found that working memory ability was a strong predictor of language class grades (Villagómez *et al*., 2017). This also includes second language learning. A study of Mexican children living in the southern USA, and receiving school instruction in English, found that the executive component of working memory was related to development in reading and language use in English (Lee Swanson *et al*., 2015).

Working memory ability is also predictive of academic achievement by children in several other fields. Working memory ability, in fact, likely helps students to learn several subjects, including history and biology (Villagómez *et al*., 2017). Researchers have particularly linked working memory to mathematical skill. Verbal skills involving numbers (such as reading aloud numbers that are written in Arabic numerals, or writing down numbers that that are dictated), or simple arithmetic performed mentally, without any aids, is also linked to efficient working memory ability. However, the same research, conducted on Argentinian children, found that more complex arithmetic involving deductive reasoning was better predicted by executive switching ability (Aran Filippetti & Richaud, 2017). In that research, as with several other studies with children, executive function was more predictive of performance than intelligence test scores.

A research study of older, high-school adolescents in Ecuador, examined which executive functions were the best predictors of overall GPA. They found that a measure of intelligence (vocabulary) did not predict GPA, but performance on an executive function test did- one that measures response inhibition (Pluck *et al*., 2019). In fact, in older students, intelligence tends to be a poor predictor of GPA. At university level, it appears that behavior self-regulation tends to be more important. In two different studies of college students in Ecuador, it was found that verbal response inhibition, a form of self-regulation, was a better predictor of GPA than intelligence (Pluck *et al*., 2016; Pluck *et al*., 2019). However, this probably depends on the material being majored in. In a separate study in Ecuador, it was found that intelligence was the best predictor of GPA for engineering students, but measures related to emotion and self-regulation were the best predictor of GPA for psychology students (Pluck, Bravo Mancero, *et al*., 2020). Interestingly, that same study provided evidence for a very different biomarker of academic achievement, which seemed to influence grades irrespective of major studied, mixed-handedness. This is when individuals have little or no preference for which hand they use in daily life. Mixed-handedness is associated with greater activation of the right frontal lobes, and linked to better learning, including language acquisition, which may be why it was associated with better GPA.

To summarize this section, academic achievement has been linked to strengths in all three of the core executive functions (working memory, switching, and inhibition), and these links are usually stronger than for intelligence test scores. However, the precise association depends on many factors, including the material being studied and the age of the students. Working memory may be the most important predictor of ability for children, but response inhibition appears to be more important a predictor for older adolescents and adults.

Executive functions and classroom misbehavior

Although there have been many studies of how executive functions predict academic achievement, there has been relatively little research on how they link to student misbehavior. This is a curious omission, considering that symptoms of the dysexecutive syndrome in neurology, such as lack of forethought, brashness, aggression, insensitivity, and recklessness, are recognizable as behaviors performed by unruly students. In fact, even in health, there is reason to link the dysexecutive syndrome to adolescent misbehavior. This is because the frontal lobes of the brain are unusually slow to develop, and may not reach maturity until age 20 or older (Blakemore & Choudhury, 2006). Before that age, adolescents are living with relatively poor executive function abilities. This, in a sense, has them in a dysexecutive state, associated with disorganized behavior.

This developmental delay in maturation of executive functions until around age 20 is quite likely a cause of the high levels of criminal and antisocial behavior committed by young adults, who have significant freedoms, but lack self-control. It is no coincidence that 19 to 20-year-olds are more likely than any other age group to commit burglary, petty theft, car theft, vandalism and arson (Steffensmeier *et al*., 1989).

We could also expect incomplete executive function and frontal lobe maturation to be a cause of classroom misbehavior. Again, data from Ecuador supports this. A study of high school students found that those who were disruptive or dishonest (i.e., arriving late for class, frequently interrupting the class, aggressive to the teacher or other students, or who cheat) tended to have worse executive functions than more well-behaved students. Specifically, poor working memory performance predicted student misbehavior (Pluck *et al.*, 2019). However, that effect was only see under high cognitive load, perhaps because the executive system is resource limited. Misbehaving students may be doing so partly, because their executive function ability is temporarily depleted.

Potential for enhancement and growth of executive functions

Many people incorrectly believe that a person's cognitive ability is an immutable factor, something that cannot be improved. In some studies, even as many as a third of teachers have indicated that they believe that cognitive level is fixed in each student. However, cognitive ability, and executive functions in particular, change in many ways, due to reasons such as ageing, health, and experiences. Many factors can result in worse, or better, executive functioning. By understanding the dynamic nature of executive function ability, we can better adjust situations to maximize brain function, classroom performance, and even general wellbeing.

Short-term fatigue and enhancement of executive functions

Neuroscience has shown that the brain is a very 'expensive organ'. Despite being only about 2% of body mass, the brain consumes about 20% of the body's energy supplies (e.g., glucose and oxygen), and most of that is consumed by the neocortex (Padamsey & Rochefort, 2023). Around one-third of the neocortex is the prefrontal cortex - the physiological substrate of executive functions. This may be one reason why executive control is so effortful. The brain cannot afford to spend too much time on attention-demanding tasks, and thus is under biological pressure to limit our use of costly concentration, problem solving, and other executive processes, hence the experience of fatigue. This may seem obvious, but none of the other cognitive processes, such as recognizing faces, recalling memories etc. are associated with fatigue. A further reason why executive attention becomes more difficult to muster, and feels more unpleasant, is that during extended executive processing, such as a long day of concentration and decision making, there is a build-up of toxic chemicals in the prefrontal cortex (Wiehler *et al*., 2022).

This toxic build up can be reversed by allowing the prefrontal cortex to rest, for example, during sleep. Also, daydreaming activates a very different brain system (the default mode network) and switches off the executive control prefrontal regions and so probably allows for the restoration of normal prefrontal-mediated execution function (Wiehler *et al*., 2022). The educational implications of this are clear. Expecting students to continuously expend their limited executive resources, maintaining attention, problem solving etc. over long periods is unrealistic. A drop-in performance cannot simply be attributed to students not trying hard enough, it is a consequence of their neurophysiology.

However, understanding this, we can apply solutions. One is that the concept of Brain Breaks (Perera *et al*., 2015), promoted by some educationalists, really does have a scientific backing. Such Brain Breaks often involve physical activity, but more placid activities, such as relaxation and breathing exercises appear to also restore the ability of students to focus in class. Furthermore, allowing sleep in schools may allow for the restoration of normal prefrontal function, which should, in turn, restore executive functions such as the ability to maintain attention, working memory, and problem solving. For both adults and children, taking naps results in a short-term improvement in executive functioning. That this contributes to learning was confirmed in an experimental study that found that naps in school also produces greater learning of class material (Lemos *et al*., 2014).

A further consideration is that if the fatigue, and drop in executive function over time, are due to depleted energy supplies (glucose and oxygen) in the brain, we may expect that replenishing this energy may also give executive processing a boost. This is exactly what is found, consuming a sugary soda drink gives short-term improvement in executive functioning. Although, there may be other considerations regarding access to sugary foods and drinks, this effect could be used at times to help students study. In fact, students are likely using this method themselves to restore cognitive processes during breaks between classes.

Many other factors also alter executive functions overt the short-term. An important factor is anxiety. Becoming worried about something has a strong negative affect on one's working memory ability. This is likely caused by the worrying thoughts themselves using up the limited cognitive and brain resources. In the classroom, some teaching practices, such as putting students at risk of embarrassment for wrong answers, likely contribute to a negative cycle in which anxiety depletes executive resources, making errors more likely (Ashcraft, 2002).

Long-term improvement of executive functions

Just as psychological states, such as anxiety, acutely influence executive function ability, over the longer-term, stressful lives can have a similar effect. In fact, prolonged stress can have negative impact on the structure of the brain, damaging executive functions. Therefore, avoiding chronic stress is an important way to improve cognitive ability. Although people find it difficult to avoid stressful situations, related with study, work or family life, they can take steps to calm the mind and bring psychological responses to stress under control.

One important way to reduce stress and improve wellbeing is to spend time in natural environments. There is much evidence that this can improve mental health and induce positive emotions, allowing people to improve their cognitive focus. One reason for this is that many people live in very artificial environments. Cities and towns have lots of square angles and flat planes, and very parallel, repetitive structures. Our brains evolved to support life as it was in paleolithic times, when people lived in very natural environments. Such environments do not have the same sensory repetitiveness of urban environments. Consequently, just perceiving urban scenes places an extra processing burden on the brain, which can be experienced as discomfort and may even cause migraine headaches (Le *et al*., 2017).

The brain, of course, is the physiological basis of all cognition, including executive processes. We often see images of the brain, indicating which parts are involved with different abilities (such as the prefrontal cortex being associated with executive function). In addition, images of neurons appear in psychology and biology textbooks, indicating how information is transmitted between cells. Although this representation is broadly correct, it can be misleading to show neurons and brain regions in such schematic ways. In reality, the neurons in the brain are living cells, that interact constantly with glia (support cells) and blood vessels. This interaction forms *neurovascular units*, which work together to process information. Problems with any part of the neurovascular unit will alter information processing, and cognitive ability.

Envisaged in this way, it becomes clear that blood physiology greatly effects the efficiency of the brain. Even a person's blood type probably influences their cognitive skill, with benefits to having the blood type O phenotype (Pluck, 2022). As neural processing is so dependent on blood flow, general health will influence cognitive ability, particularly executive functioning. As such, the brain is sensitive to hydration level, nutrition, substance use, etc. Anything that improves metabolism, and circulatory health, such as healthy diet and regular exercise, will potentially allow for better cognitive ability. Of course, this will also contribute to better well-being overall.

People often overlook what is probably the most powerful method that we have available for improving cognition- education. There is strong evidence that education improves overall cognitive ability. And this increase is considerable. If we use IQ as a general measure of cognitive skill, every year spent in formal education causes an increase in IQ of about 2 or 3 points. Importantly, this is not simply accumulation of knowledge, but actual improvements in fluid aspects of cognition, including working memory (Judd *et al.*, 2022). Even short training courses may have small positive effects on wellbeing and executive functioning. A six-week intervention to aid young, unemployed people from various countries in Latin America reduced distress, improved self-esteem, and improved cognitive inhibition ability (Crespo-Andrade *et al.*, 2022).

Of course, gaining education to improve executive functions, to improve academic achievement is rather circular. However, maximizing one's cognitive ability has multiple benefits, beyond academic achievement. People with better cognitive ability are at reduced risk of a wide range of illnesses involving the brain, including mental health and neurological illness. This phenomenon, known as cognitive reserve, shows that improved cognitive ability provides resilience against illnesses, and also improved functional ability in older age. Executive function appears to be one core factors that provides this resilience. Furthermore, better cognitive ability, including executive function, has only ever positive consequences across a wide range of lifestyle and well-being factors, such as income, family stability, and happiness (Brown *et al*., 2021).

Conclusions

Executive functions, associated with the frontal lobes of the brain, are the abilities that allow us to pursue goals and to act intelligently. As such they are important predictors of achievement and (mis) behavior, with substantial implications for understanding education. Two important skills in respect to achievement are working memory, particularly in children, and response inhibition in adolescents (and adults in the workplace). Working memory also appears to be important in relation to classroom misbehavior. Fortunately, executive functions such as these can be improved in many ways, with positive impacts on learning, health, and well-being. Maintaining good general physical and mental health is an important factor in allowing executive cognitive ability to function efficiently. Probably the most powerful method of improving them is through formal education and training.

Interest conflict

The authors report no conflict of interest.

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