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Review

The Importance of the Environment as a Driver of Knowledge: Does Socio-Economic Status Matter?

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Abstract: Brain plasticity or brain reorganization is important for satisfactory cognitive activity, in which the learning process can guarantee the skills needed for full personal development. Socioeconomic status, which presents the social reality of the individual, such as educational level, income, health and neighborhood, is an important factor for learning and the anatomical characteristics of the brain to function normally. Our aim, through a narrative review, was to update the current state of the art, and in this way we carried out a wide-ranging study that discusses SES and cognition, in order to show that SES has a positive impact on learning when social conditions are favorable and a negative influence, both on brain structure and on the learning process, when social conditions are not favorable. In view of this, it is necessary to think about strategies that enable equal opportunities in the learning environment and public policies that can remedy inequalities and boost knowledge.

Keywords: Socioeconomics Status; Environment; Learning; Memory.

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1. Introduction

Brain plasticity, or neuroplasticity, means the reorganization of the brain - molecular, cellular and functional - in the face of a new stimulus, experience or environmental exposure. It consists of the ability of nerve, immune and endocrine cells to create neuronal connections, promoting new functions in the nervous system. These neuroplastic changes can be acute or occur over time, where they can be positive or negative, reorganizing themselves in response to normal body development/maturation, experience, the acquisition of new skills, sensory stimulation, deprivation and injury [1-3].

With this information, it can be said that learning and memory are cognitive functions that encompass a variety of subcomponents that are structured in different ways4. Learning is the product of a dynamic and interactive process with the world around us and is associated with personal development. Through learning, it is possible to develop competencies, skills, knowledge, behaviors and values, which are acquired through experiences, observations and studies. Memory, in turn, is an active process of classifying, coding, storing, consolidating and recalling knowledge acquired through learning processes. Learning, therefore, is the result of the interaction between the various types of memory (explicit and implicit, long and short term) and both the learning process and memory are directly impacted by the environment and socioeconomic status [5, 6].

Socioeconomic status (SES) is a broad concept with multiple presentations and can be operationalized in various ways, using individual variables or composite measures derived from them. Educational level, occupation and income are variables that are usually considered when characterizing an individual's socioeconomic status [7]. In this sense, a robust body of recent research points to associations between brain development in childhood and this important marker of social position, i.e. SES, influencing attention, memory, language, learning and executive functions [8].

With this information, socioeconomic disadvantage among children and adolescents predicts a series of negative outcomes in cognition, physical health, mental health and academic performance [9]. School-age children and adolescents of low socioeconomic status are predisposed to a range of negative health risks throughout their lives [8]. There are several complex factors that can determine this relationship: poor diet, obesity, not practicing physical exercise, longer screen time, the environment in which they live, maternal mental health, family income, among others [9]. All these factors are associated with various deficits in brain structure and cognition and have a huge impact on cognitive development, showing that low socioeconomic status affects neuroplasticity and therefore learning [9-12].

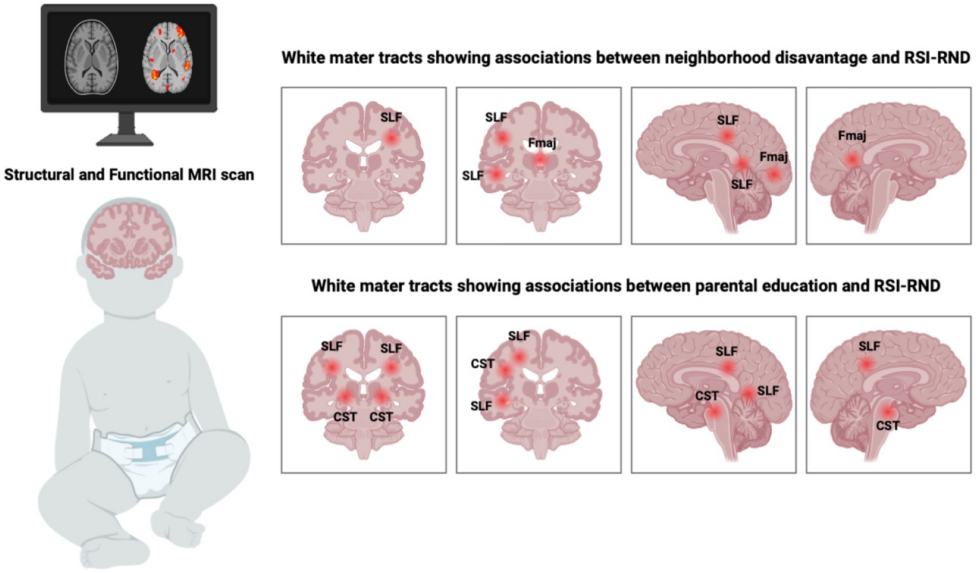
In view of the above, environmental factors such as socioeconomic status are important in modulating memory and learning in children and adolescents, which should be the focus of public education policies. This study aims to update the current state of the art on the impact of low socioeconomic status on learning.

2. Socioeconomic Status and the Structure of the Nervous System

In a cross-sectional study of 8.842 children participating in an Adolescent Brain Cognitive Development survey, low SES had independent associations with lower restricted directional diffusion and higher restricted isotropic diffusion in white matter (Figure 1) [9]. Among 31 total white matter tracts, lower SES was associated with lower RSI-RND (restricted normalized directional diffusion-restricted spectrum imaging) in 5 tracts: corticospinal or pyramidal tract (bilateral CST), forceps major, superior longitudinal fasciculus (bilateral SLF [including bilateral temporal-SLF and bilateral parietal-SLF), higher RSI-RNI (reflecting glial and neuronal cell bodies) in 24 tracts: bilateral fornix (bilateral Fx), bilateral cingulum, bilateral parahippocampal cingulum (bilateral CgH), bilateral CST, bilateral anterior thalamic radiations (bilateral ATRs), bilateral uncinate fasciculus (bilateral Unc), bilateral inferior longitudinal fasciculus (bilateral ILF), bilateral inferior occipitofrontal fasciculus, corpus callosum [including forceps major and forceps minor], bilateral SLF [including left tSLF and bilateral pSLF], bilateral superior corticostriatal tract (right-left SCS), bilateral inferior cortical tract to bilateral inferior frontal cortical tract and bilateral inferior frontal cortical tract) and inferior DTI-FA (diffusion tensor imaging fractional anisotropy) in 6 tracts (left Fx, bilateral CST, bilateral SLF [including bilateral tSLF and bilateral pSLF], and left SCS) [9].

In this sense, a cross-sectional study by Rakesh et al. with 8,862 children aged 9 to 10 found similar results involving socioeconomic status and brain structure. There were 4243 girls (47.9%) and 4619 boys (52.1%). The authors found that neighborhood disadvantage was independently associated with the cortical thickness of brain regions in the frontal, parietal and occipital lobes. The income-need ratio was independently associated with the thickness of the parahippocampus. In addition, they found that different indicators of SES had synergistic associations, so that the association between neighborhood disadvantage or low educational attainment and reduced cortical thickness was less pronounced in the presence of high income-need ratios. In general, the effect sizes were small, with the percentage of variance in brain structure explained by the SES indices ranging from 0.003 to 0.009. Interestingly, the lateral orbitofrontal cortex, in addition to the medial and lateral occipital regions, was sensitive to the presence of a high income-need ratio. These findings indicate that the regions of the occipital cortex are particularly sensitive to different aspects of the socioeconomic context [13].

Figure 1. Associations Between Socioeconomic Status and White Matter Restriction Spectrum Imaging (RSI) Restricted Normalized Directional (RND) Diffusion. SLF: superior longitudinal fasciculus. CST: corticospinal tract. Fmaj: forceps major.



Also, along these lines, in a diverse sample of 1.082 children and adolescents aged 3 to 21, socioeconomic disparities in the macrostructure and microstructure of the white matter were examined. The relationships between family SES, the volume and integrity of children's white matter in the sectors that support executive function (EF) and performance on EF tasks were also investigated. Higher family income was associated with greater fractional anisotropy (FA) in the right parahippocampal cingulum ($\beta = 0.101$, $p = .001$) and in the right superior corticostriatal tract in the frontal cortex ($\beta = 0.095$, $p = .001$). There was no significant relationship between family income and white matter volume. Higher parental schooling was associated with higher PA in the left superior parietal cortex ($\beta = 0.088$, $p = .001$). Higher parental education was associated with lower white matter volume in the left superior inferior frontal cortex tract ($\beta = -0.063$, $p < .001$) [14].

On the other hand, socioeconomic status was associated with fractional anisotropy (FA) and volume in multiple white matter tracts. In addition, family income moderated the relationship between white matter structure and cognitive flexibility. Specifically, in several sectors of interest, lower FA or volume was associated with reduced cognitive flexibility among children from low-income families. In contrast, children from higher-income families showed preserved cognitive flexibility in the face of low white matter volume or PA. These results suggest that children from higher-income families may be buffered from behavioral deficits that are typically associated with lower white matter volume and integrity. As such, this result adds to a growing body of literature suggesting that the socioeconomic contexts in which children develop not only shape cognitive functioning and its underlying neurobiology but may also shape the relationships between brain and behavior [14]. Material deprivation, stress and environmental toxins are environmental mediators that can link SES to brain development through a set of biological mechanisms. Brain regions that process and respond to threat, regulate stress response and support language, literacy and executive functions may be particularly vulnerable to these SES-related factors. The prolonged development of brain areas that support these cognitive processes (e.g. language regions of the temporal lobe, amygdala, hippocampus, prefrontal cortex) makes these areas particularly vulnerable to environmental input [15].

In a study carried out by Satterthwaite et al. [16] and described by Murtha et al. (2023), the impact of socioeconomic status (SES) on brain functioning during the n-back task, which measures working memory, was analyzed. The results indicated that higher

SES, both family and neighborhood, was associated with greater activation of areas of the brain's executive system, such as the dorsolateral prefrontal cortex, anterior insula and supplementary motor area, among others. These regions are fundamental for executive and cognitive processing. In addition, greater deactivation was observed in areas of the default mode network, which is generally less active during tasks that require attention. Parental education also showed a strong correlation with the activation of various regions of the executive system. These findings suggest that higher SES favors more efficient recruitment of brain networks involved in executive and cognitive functions [16].

Finally, one study analyzed how socioeconomic status (SES) influences brain structure and function, particularly in relation to working memory (WM) and academic performance. No variations in cortical thickness were found based on SES, but a correlation was identified between low SES home environments, with little cognitive stimulation, and a thinner cortex in the frontoparietal regions. Previous studies have also documented SES-related differences in the microstructure of the white matter in the frontoparietal tract that impact MT and academic performance. In addition, greater activation of the prefrontal cortex and occipital-temporal cortex during MT tasks was observed in higher SES children, correlating with better academic and MT performance. The research concluded that cognitive stimulation, MT performance, and frontoparietal network integrity are critical mediators between SES and academic performance, suggesting that environmental, neural, and cognitive factors are key to understanding the educational disparities associated with SES [17].

3. Socioeconomic Status, Child Development and Schooling

The hippocampus, an essential brain structure, plays a crucial role in learning and memory. However, it is particularly vulnerable to the effects of stress due to the density of glucocorticoid receptors [15]. Studies investigating the relationship between family socioeconomic status (SES) and hippocampus size in children and adolescents reveal some findings: the relationship between SES and hippocampus size: children from higher SES families tend to have larger hippocampus; children raised in a low SES environment have smaller hippocampus, even when adjusted for socioeconomic circumstances in adulthood; mediation between stress and parenting: chronic stress and parenting play an important role in the relationship between family SES and child hippocampal structure; less supportive and more hostile parents may mediate this relationship, affecting children's hippocampal volume years later; and sensitive periods and education: sensitive periods during development also influence hippocampal size; children deprived of parental nurturance early in life may experience delayed hippocampal maturation during adolescence. Both material resources and the parental environment play a formative role in the development of the hippocampus, highlighting the importance of these factors for brain health throughout life [15].

The process of cognitive enrichment refers to exposure to a complex environment with diverse experiences and learning materials. Children raised in homes with higher socioeconomic status tend to have more cognitively stimulating environments. This cognitive stimulation is associated with improvements in cognition, regardless of stress. Recent studies indicate that deprivation of a stimulating environment presupposes an absence of cognitive enrichment, and this absence can accelerate synaptic pruning in various brain areas involved in processing complex cognitive and social stimuli. Therefore, varied childhood experiences shape the pace of brain development and its plasticity throughout life, resulting in more efficient cortical networks in adulthood [18].

On the other hand, during adolescence, environmental factors (such as socioeconomic status - SES) and genetic factors play a crucial role in cognitive and brain development. One study investigated independent associations between SES and a genetic score related to educational level (EduYears-PGS). Although these determinants are correlated, they independently influence cognition and brain development. Both SES and EduYears-PGS are associated with total cortical area at age 14, with SES affecting globally

and EduYears-PGS regionally. In addition, SES remains relevant for changes in brain surface area between the ages of 14 and 1919. Thus, a study investigated the relationship between different indicators of socioeconomic status (maternal schooling, paternal schooling and neighborhood SES) and the educational level of adolescents at the age of 17. The results showed that both maternal and paternal schooling are positively associated with adolescents' schooling, independently. Adolescents with highly educated mothers are more likely to achieve a higher level of education. This trend also applies to paternal schooling. However, no association was found between neighborhood SES and adolescent educational attainment, and there is no evidence of interactions between parental educational attainment [20].

Families of low socioeconomic status often face financial constraints and have limited access to community resources, high-quality education and early care. These limitations affect children's opportunities for critical cognitive, social and emotional stimulation. In addition, these families face additional adversities, such as food insecurity, poor health and community violence. These experiences play an important role in the differences observed in children's executive function and social and emotional skills. The neural circuits underlying executive function are particularly sensitive to experiences during early childhood. Neuroimaging studies show changes in brain activation from infancy to 4-5 years, probably due to accelerated myelination. This perspective on neurodevelopment highlights the importance of early experiences in shaping the brain. In addition, differences in prefrontal cortex activation in executive function tasks between low and high socioeconomic status are evident even before kindergarten entry [21].

Finally, we can note that a population-level study investigated the association between the prevalence of health disorders in preschool children and the socioeconomic status (SES) of the neighborhood in which they live in Canadian jurisdictions. The results indicated that children living in poorer neighborhoods were more likely to have health problems at school entry. This association varied according to jurisdiction. In addition, previous studies have also shown that children with disabilities in kindergarten were proportionally more likely to have worse developmental health when they lived in lower SES neighborhoods. These findings highlight the importance of the conditions of the environment in which children grow up and their impact on health and development. The availability of programs and the distribution of health professionals and services can also influence these variations [22].

4. Socioeconomic Status, Memory and Learning

One study examined cognition (i.e., memory and language/executive function) among more than 3,000 men and women who graduated from Wisconsin high schools in 195723. Approximately a quarter of the participants carried one or more ε4 alleles of the APOE gene, a risk factor for cognitive impairment in late life. The main objective of this study was to examine the extent to which SES in childhood moderates the associations between being an ε4 carrier and cognition in late life - both in terms of baseline levels of cognition and change in cognition over 7 years. The results showed that APOE ε4 was not associated with baseline levels or change in language/executive function but was associated with declines in memory. The findings further indicated that being an APOE ε4 carrier was associated with differential susceptibility to childhood SES: ε4 carriers from disadvantaged families had the poorest memory at baseline, while ε4 carriers from advantaged families had the best memory at baseline [23].

On the other hand, a study using Chinese eighth graders as subjects investigated the relationship between the level of education, the professional prestige of the parents and family property (indicators of socioeconomic status - SES) and reading ability estimated by item response theory (IRT) techniques. The results indicate that family SES is correlated with the students' reading ability. The higher the parents' schooling, occupational prestige and income, the higher the children's reading ability, and vice versa. This positive link between SES and children's performance is well established. However, this re-

lationship is complex, as different components of SES affect reading ability in different ways. Parental education is an important indicator of SES and a significant predictor of children's educational performance. Parents with lower educational attainment may not have sufficient skill or emphasis to provide adequate tutoring for their children's academic performance, which can result in accumulated academic difficulties over time [24].

Based on the information provided, previous studies on the association between Socioeconomic Status (SES) and Delayed Reward Discomfort (DRD) involved adults whose SES was assessed based on parameters such as parental income during childhood or current annual income. The study also found a negative association between family SES and DRD, which is in line with previous research that has focused on the relationship between childhood SES and DRD in adults. This suggests that this negative relationship is already present during adolescence. In addition, childhood SES showed a significant association with several cognitive measures. This finding indicates that the cognitive effects of low SES observed during early and middle childhood continue to persist in adolescence. However, it is important to note that only one of the working memory (WM) measures, specifically performance on the running memory (RM) task, showed a significant and positive association with DRD [25].

Based on the information provided, previous studies on the association between SES and DRD involved adults whose SES was assessed based on parameters such as parental income during childhood or current annual income. The study also found a negative association between family SES and DRD, which is in line with previous research that has focused on the relationship between childhood SES and DRD in adults. This suggests that this negative relationship is already present during adolescence. In addition, childhood SES showed a significant association with several cognitive measures. This finding indicates that the cognitive effects of low SES observed during early and middle childhood continue to persist in adolescence. However, it is important to note that only one of the working memory (WM) measures, specifically performance on the running memory (RM) task, showed a significant and positive association with DRD [25]. With this information, the results consistently showed that socioeconomic disadvantage at birth was associated with lower working memory performance in middle childhood. This supports the view that SES influences MT.

Currently, the difference between the “most and least deprived” group was equivalent to an age difference of 12 to 18 months. Previous literature on this topic was inconsistent in the type of task used to measure MT, with some measuring storage, some measuring processing capacity and others combining these scores into a composite measure; therefore, the idea of the research was to examine these components separately. The results showed that the biggest gap is related to performance on the working memory task that measures the ability to process and manipulate information (the BDR task). Substantial variation was also found in MT scores by ethnicity, and this variation depended on the type of MT task and the ethnic group. Most ethnic minority groups scored higher than white British children on at least one MT measure. This finding contrasts with the few existing studies that have looked at ethnic differences in children's MT, where it has been found that minority ethnic groups tend to have lower MT scores. Since the study focused on socioeconomic and ethnic group differences in working memory, the mechanisms behind ethnic differences in children's MT remain unexplained [26].

On the other hand, a sample of 385 students, with 205 in the low socioeconomic status group and 180 in the medium-high socioeconomic status group, analyzed the three central executive functions (CEFs), inhibition, working memory and cognitive flexibility, as mediators between socioeconomic status (SES) and academic performance in Chinese schoolchildren. A structural equation model showed that the SES-academic performance relationship was mediated by cognitive flexibility and working memory (WM), but not by inhibition. Working memory was a much stronger mediator than cognitive flexibility, suggesting that MT may correlate with childhood SES and academic performance in

Chinese children. An analysis of covariance showed that, compared to the medium-high socioeconomic status group, the low socioeconomic status group demonstrated worse working memory and academic performance in all three subjects after controlling for age and IQ. Interestingly, the children with low SES showed better cognitive flexibility than the children with medium-high SES. These findings suggest that interventions targeting working memory may be a relevant area for improving children's academic performance [27].

One study investigated the neural mechanisms underlying visuospatial memory deficits in young adults with a history of childhood poverty. It found that childhood income and hippocampal function in visuospatial memory performance presents a novel link between hippocampal function in association with visuospatial memory performance and childhood poverty history. It was shown that towards higher levels of childhood income, there was a predicted positive association between hippocampal activation and memory performance. On the other hand, towards lower levels of child income, the association between memory performance and hippocampal activation was negative (i.e. more activation was associated with worse memory performance). No association was found between neural activation in the hippocampus during encoding and performance on the subsequent recognition task in all subjects, in contrast to a previous report of hippocampal engagement in both encoding and recognition of information [28].

5. Socioeconomic Status and Mental Health

Mental health is an expression used to describe the level of cognitive or emotional quality of an individual, so this research sought to investigate the impact of SES on health and explore the mediating effect of lifestyle. The study by Wang [29] defined a structural model of mediation and produced important findings, including that SES may be one of the most decisive social factors affecting an individual's health and life expectancy. In relation to physical health, the impact of SES involves three main aspects: occupation, income and education [30]. Previous research has revealed that people with higher occupational status enjoy greater autonomy at work, engage in less manual labor, are less exposed to health risks and have greater health-related awareness and knowledge31. However, the hypothesis that people with higher socioeconomic status are in better psychological health has not been approved. Some research has reported that low SES is associated with the prevalence of psychological distress, depression, anxiety and anguish. There is evidence to imply that mental health has no significant relevance to SES. A more plausible conclusion could be that the relationship between SES and psychological health is different between different mental illnesses [29].

Psychiatric disorders are known to be a global problem that burdens individuals and society [32]. The study by Shao et al. was able to present relevant findings on the subject: subjective SES was more strongly related to mental health status than objective SES among Chinese migrant workers; perceived interpersonal discrimination mediated the direct relationship between subjective SES and mental health, but did not mediate the direct relationship between objective SES and mental health. The explanation may lie in the processes of social comparison, in which people's “happiness”, a key aspect of mental health, depends on comparisons with the surrounding population and not with the distant population; and finally, age moderated the indirect relationship between subjective SES and mental health through perceived interpersonal discrimination, and this mediated link was stronger for older people. These findings differ from those of Wang et al. who showed that the impact of SES has a greater effect on physical health [29]. People with higher subjective SES have less psychological stress and therefore fewer mental health problems. Furthermore, interpersonal discrimination is linked to mental health problems and can be considered a chronic socio-environmental stressor [33].

With this information, another study highlights the importance of understanding how neighborhood environments shaped mental health over time among women survivors of Hurricane Katrina, a particularly vulnerable population that experienced

post-disaster displacement and migration [34]. The impact of neighborhood-level socioeconomic conditions on individual-level mental health was examined using a composite measure of neighborhood SES. It turned out that an increase in neighborhood SES was associated with an increase in mental health [35]. Furthermore, women who returned to their pre-disaster communities were predicted to have better mental health compared to women who did not return. The findings shed light on the need for further studies between the relationship: displacement and mental health; the need to explore other dimensions of neighborhood SES conditions that are relevant to women's mental health and well-being; and the connection of survivors to mental health services and housing assistance programs after natural disasters [34].

On the other hand, adolescent mental health is a major public health problem that cannot be ignored, and mental health problems are one of the main causes of physical illness in adolescents and children worldwide [36]. This study used the entropy weight method to synthesize family socioeconomic status based on the following indicators: family income, parents' schooling and parents' occupation. Family SES, family income and parental education were found to have significant effects on adolescents' mental health37. These results are robust. The mental health of individuals who have not studied health courses and who have a registered agricultural residence are more affected by the socioeconomic level of the family. In addition, two mechanisms of the effect of family socioeconomic status on adolescents' mental health have been established: the frequency of parent-child interaction and the frequency of interaction with peers [38].

Based on the information provided, a study concluded that the impact of stressful life situations on the mental health of children and adolescents depends on Socioeconomic Status (SES). Children from families with low SES have a higher risk of facing different stressful situations. In addition, the experience of stress in life is associated with mental health problems in this group. Therefore, it is crucial to consider not only traditional indicators of SES, such as family income, parental education or occupation, but also the broader current life situation, including various sources of stress. Notably, children with less educated parents need more support to deal with stressful situations, such as parental illnesses, accidents or serious financial crises, compared to their peers whose parents have more education [39].

Finally, this study presented the neighborhood effects on the relationship between SES and mental health, experimentally testing various contextual mechanisms related to the socio-interactive environment of neighborhoods. According to Barakat's studies, social mobility has a general impact on health. Those who experience upward social mobility have better health outcomes throughout life than those who experience downward social mobility [31]. Higher levels of SES, social interaction, trust, participation in the neighborhood organization (NOP), attachment and security were found to be significantly associated with higher levels of mental health, even controlling individual-level factors. However, this interaction was no longer significant after controlling other neighborhood characteristics. In single mediation models, neighborhood social interaction significantly mediated the relationship between SES and mental health. In a multiple mediation model, only neighborhood trust was a significant mediator. These results indicate that good mental health associated with living in wealthier neighborhoods is partially explained by higher levels of mutual trust and neighborhood social-interaction characteristics [40].

6. Conclusion

Socioeconomic status is a relevant factor in a learning environment. Noting that the SES points to differences in cognitive and structural brain development makes us think about creating strategies that enable equal opportunities in the learning environment. Public policies must be expanded to remedy inequalities and boost knowledge.

To learn, there needs to be a very complex interaction between the biological being, the psychological being and the socio-cultural environment. In this sense, a child who

lacks basic nutrition or who doesn't sleep properly has a damaged biological apparatus. This has numerous negative implications for learning. In this way, our article contributes by showing the main elements of learning and education to take place in an acceptable and desirable way.

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