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Assessing cognitive flexibility: Quantitative insights into the impact of adaptive learning technologies in special education

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A B S T R A C T

This study employed quantitative methods to evaluate the influence of adaptive learning technology on the cognitive flexibility of students with special needs. Participants were recruited from special education schools using a purposive selection strategy. The Wisconsin Card Sorting Test (WCST) was utilized as a tool to assess cognitive flexibility. The data was analyzed using descriptive statistics, paired-samples t-test, correlation analysis, and regression analyses. The findings demonstrated a notable enhancement in WCST scores after the intervention, suggesting that adaptive learning technologies have a beneficial effect on cognitive flexibility. Regression studies revealed that various types of adaptive learning technologies had varied levels of efficacy, with Tech A showing the most significant beneficial impact. Surprisingly, demographic factors such as age, gender, and educational attainment demonstrated little and statistically insignificant associations with alterations in cognitive flexibility levels. The findings emphasize the potential of adaptive learning technologies as effective therapies for improving cognitive flexibility in kids with special needs. It underscores the significance of evaluating specific characteristics and design principles to maximize their efficacy.

1. Introduction

Cognitive flexibility is a crucial concept that refers to an individual's ability to adjust their thoughts and behavior to meet the demands of a changing environment. The concept involves the capacity to change mental frameworks, create other options, and adjust approaches when confronted with new circumstances or challenges (Schmitz & Krämer, 2023; Podlogar & Podlesek, 2022). Developing cognitive flexibility is especially important for individuals with special needs, since it forms the foundation for a range of academic and social abilities, such as problem-solving, decision-making, and social interaction (Ellis, 1995; Tsomokos & Flouri, 2023). Nevertheless, individuals in this group typically face significant obstacles in developing cognitive flexibility due to cognitive impairments or learning difficulties. Recently, the incorporation of adaptive learning technology into special education programs has become a viable approach for promoting cognitive flexibility in individuals with various learning requirements. Adaptive learning technologies utilize algorithms to customize instructional content and speed to match the capacities of individual students, offering tailored learning experiences that can cater to various learning styles and cognitive profiles (Hamer & Lely, 2020; Lee & Boo, 2022). Using scaffolding teaching, providing quick feedback, and adjusting difficulty levels, these technologies have the ability to improve cognitive flexibility by implementing specific treatments and repeated practice (Boswell, 2023; Hadfield, 2020).

Although there is an increasing amount of research investigating the effectiveness of adaptive learning technologies in special education, there is less quantitative information about their influence on cognitive flexibility. Prior research has mostly

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concentrated on qualitative evaluations or subjective indicators of cognitive flexibility, offering restricted understanding of the extent and applicability of the impacts of these technologies. Hence, there is an urgent requirement for thorough quantitative research to methodically assess the efficacy of adaptive learning technologies in enhancing cognitive flexibility among children with special needs. The objective of this study is to fill this void by undertaking a thorough quantitative evaluation of the influence of adaptive learning technologies on cognitive flexibility in special education environments. We want to use strong research methods and reliable assessment techniques to gather empirical data that explains how adaptive learning technology can improve cognitive flexibility in this group of people. To direct our inquiry, we rely on a strong theoretical basis that emphasizes the interaction between adaptive learning technologies and cognitive flexibility. Cognitive flexibility theory suggests that individuals have different levels of cognitive flexibility, which may be affected by aspects in their environment, teaching methods, and the demands of the work at (Fukuzaki & Takeda, 2022; Uhlig et al., 2022). Adaptive learning technologies are believed to support the development of cognitive flexibility through their adaptive algorithms and personalized feedback mechanisms. They provide customized learning experiences that cater to individual differences and encourage active participation (Sievert et al., 2019).

Furthermore, recent breakthroughs in educational neuroscience have provided insight into the neurobiological foundations of cognitive flexibility and how it might be influenced by adaptive learning technology. Neuroimaging studies have shown the brain areas and connections involved in cognitive flexibility, including the prefrontal cortex and its interactions with subcortical structures, which play a role in executive control and adaptive behavior (Friedman & Robbins, 2021). This work seeks to establish a connection between the improvement of cognitive flexibility through adaptive learning technologies and the underlying brain processes. By doing so, it attempts to provide a more thorough knowledge of the impacts of these technologies by linking behavioral results with neurobiological substrates.

1.1 Problem of the Study

Although there have been improvements in adaptive learning technology, there is still a notable lack of comprehension of their measurable influence on the cognitive flexibility of children with special needs. Although the theoretical foundations propose that adaptive learning technology can improve cognitive flexibility through tailored learning experiences, there is insufficient actual data to support this claim. The current body of research primarily depends on qualitative evaluations or subjective metrics, which may not accurately represent the exact extent and applicability of these technologies' impact on cognitive flexibility. Hence, it is imperative to conduct rigorous quantitative research to systematically assess the effectiveness of adaptive learning technologies in enhancing cognitive flexibility in special education environments.

Research Questions

1. What is the quantitative impact of adaptive learning technologies on cognitive flexibility among students with special needs?
2. How does the effectiveness of different types of adaptive learning technologies vary in fostering cognitive flexibility?
3. What factors influence the effectiveness of adaptive learning technologies in promoting cognitive flexibility among students with special needs?

Significance of the Study

The findings of this study have important implications for the theoretical, practical, and policy aspects of special education. This research intends to offer empirical data that statistically assesses the influence of adaptive learning technologies on cognitive flexibility. It seeks to understand the efficacy and mechanisms underlying the incorporation of these technologies in special education situations. These findings may be used to create evidence-based strategies to serve kids with unique needs and build customized therapies to improve cognitive flexibility. Furthermore, the results of this study can provide valuable insights to educators, policymakers, and technology innovators regarding the efficacy of adaptive learning technologies in tackling the complex difficulties related to cognitive flexibility impairments in students with special needs. This research aims to uncover the variables that impact the efficacy of these technologies, to provide guidance for designing and implementing more focused interventions that optimize cognitive flexibility results. Moreover, this research enhances the existing body of knowledge on cognitive flexibility and educational technology by deepening our comprehension of the interaction between adaptive learning technologies and cognitive functions in special education environments. This research aims to provide a connection between theoretical frameworks and empirical data. It serves as a fundamental step in utilizing adaptive learning technology to enable all learners to attain cognitive flexibility and academic achievement.

Term of the Study

This study used a quantitative research design to evaluate the influence of adaptive learning technology on the cognitive flexibility of students with special needs. The study was carried out in specialized educational environments, employing recognized assessment instruments to determine cognitive flexibility results. The study aimed to assess several forms of adaptive learning technologies, such as intelligent tutoring systems, instructional games, and personalized learning platforms. Data

were gathered using pre-test/post-test evaluations, and statistical analysis will be performed to investigate the efficacy of these technologies and uncover potential influential factors.

Limitations of the Study

Although this study seeks to offer vital insights into the influence of adaptive learning technology on cognitive flexibility in special education, it is important to recognize numerous limitations. Firstly, the applicability of the findings may be restricted due to the circumstances and features of the study's sample. In addition, the dependence on quantitative measures may fail to consider subtle features of cognitive flexibility that qualitative techniques may capture. Furthermore, this study may not completely consider the impact of implementation fidelity, student involvement, and individual variations in learning styles on the efficacy of adaptive learning technology. Ultimately, the limited duration of the intervention and evaluation may fail to reflect the enduring impact on the growth of cognitive flexibility. Notwithstanding these constraints, our research signifies a crucial progression in enhancing our comprehension of the function of adaptive learning technologies in fostering cognitive flexibility among children with exceptional needs.

2. Literature review and Previous studies

Cognitive flexibility is a crucial cognitive ability that allows individuals to adapt their ideas and actions to changing environmental requirements (Ionescu, 2012). Cognitive flexibility is essential in the field of special education as it plays a critical role in improving various academic and social skills. These skills encompass the ability to solve problems, make decisions, and engage in social interactions (Birch, 1994; Chudzik & Corr, 2023). However, persons with special needs often have challenges in developing and maintaining cognitive flexibility due to learning disabilities (Trute, 2017). Adaptive learning technologies are becoming more effective tools that help in fostering cognitive flexibility in children with special needs. These technologies employ algorithms to tailor education and provide individualized learning experiences that accommodate various learning styles and cognitive profiles (Zenkina & Yusova, 2023). Adaptive learning technologies aim to enhance cognitive flexibility by offering targeted interventions and repeated practice. They achieve this through instructional assistance, timely feedback, and personalized difficulty levels (Henshall et al., 2022). While there is a substantial body of research on adaptive learning technology in special education, further studies are required to particularly investigate their impact on cognitive flexibility. However, other research has provided insights into related areas, offering useful insights into understanding the possible effects of adaptive learning technologies on cognitive flexibility.

For instance, a captivating investigation conducted by Dawidowsky (2019) explored the realm of computer-based treatments and their influence on executive processes. Their primary focus was on investigating how these therapies may improve cognitive flexibility in children who have been diagnosed with attention deficit hyperactivity disorder (ADHD). The study was conducted longitudinally and yielded useful insights in this field. The study's results demonstrated significant improvements in cognitive flexibility abilities following the session, highlighting the potential of technology-based therapies to address cognitive flexibility impairments in clinical populations. Goldstein et al. (2015) conducted a study to investigate the effects of contemporary mathematics computer games on the academic performance and motivation of middle school pupils. The study did not specifically measure cognitive flexibility, nonetheless, the findings demonstrated significant improvements in academic performance and engagement. These findings indicate that the use of technology in learning might potentially influence the development of cognitive flexibility in an indirect manner. In addition, the study done by Eschmann & Eberhard (2021) evaluated the influence of metacognitive and emotional self-regulatory processes on learning using multi-agent systems. The study analyzed many facets of self-regulation and emphasized the importance of adaptable learning settings in promoting active involvement and self-directed learning. These elements are essential in the formation of cognitive flexibility.

3. Methods

The study utilized a quantitative research design to evaluate the influence of adaptive learning technology on the cognitive flexibility of students with special needs. The study employed a purposive sample strategy to choose participants from special education schools located in the specified geographical area. Prior to their participation in the study, both the subjects and their legal guardians were gained informed permission. A purposive sampling approach was selected to guarantee that participants fulfilled inclusion requirements, such as having a diagnosed learning disability or cognitive impairment and being enrolled in a special education program. This method enabled the choice of a uniform sample of individuals with comparable traits, hence improving the internal validity of the study. The Wisconsin Card Sorting Test (WCST) was employed as the cognitive flexibility measurement tool, which is a highly recognized neuropsychological assessment instrument extensively utilized in both research and clinical environments. The WCST evaluates cognitive flexibility by presenting participants with card sorting problems that need the application of various sorting principles and the ability to adjust tactics in accordance with changing rules. Prior research has thoroughly verified the reliability and validity of the WCST, establishing strong psychometric features for evaluating cognitive flexibility. Before collecting data, the WCST was verified for its suitability with the specific group of kids with exceptional needs. The validation method entailed conducting a pilot test of the WCST with a limited number of students to verify that the task instructions were unambiguous and easily understood, and that the test stimuli were suitable and captivating for the participants. In addition, the WCST was conducted by proficient assessors who were well-versed in standardized administration methods to reduce mistakes in administration and guarantee uniformity across

participants. To assess the impact of adaptive learning technology on cognitive flexibility, the collected data were analyzed using appropriate statistical approaches. The dimensions and mean scores of the pre- and post-tests were calculated with more precision. Researchers computed the effect size to determine the efficacy of the adaptive learning intervention in improving the WCST and to see if there was a significant improvement in cognitive flexibility following the intervention. We got the result we wanted by using the Eta square. Two samples with identical features were compared for degree of dissimilarity using the Z-value and the Wilcoxon test. In addition, correlational analyses were performed to investigate the impact of demographic characteristics (such as age and gender) on changes in WCST scores, to understand the possible factors that influence the efficiency of adaptive learning technologies in increasing cognitive flexibility. In addition, regression analysis was used to evaluate the predictive efficacy of various adaptive learning systems on cognitive flexibility results, while accounting for any confounding factors.

4. Results

Table 1 shows that before the adaptive learning technologies training program was implemented, the researchers made sure that the experimental and control groups had similar degrees of cognitive flexibility based on WCST.

Table 1
Pre-test

Dimension	Groups	N	M/R	S/R	U	Z	P
Categories Completed	Experimental	15	9.40	141.00	60.00	1.480	0.490
	Control	15	9.80	147.00			
FMS	Experimental	15	10.55	158.25	33.20	1.115	0.805
	Control	15	10.40	156.00			
Perseverative Errors	Experimental	15	9.70	145.50	55.00	1.360	0.590
	Control	15	9.90	148.50			
Perseverative Responses	Experimental	15	10.65	159.75	32.00	1.125	0.780
	Control	15	9.70	145.50			
Non Perseverative Errors	Experimental	15	10.10	151.50	35.00	1.180	0.750
	Control	15	10.00	150.00			
Trials to First Category	Experimental	15	9.50	142.50	58.00	1.450	0.510
	Control	15	9.40	141.00			
Number Correct	Experimental	15	9.00	135.00	62.00	1.535	0.380
	Control	15	8.90	133.50			
Number of Trials	Experimental	15	8.50	127.50	65.00	1.560	0.320
	Control	15	8.40	126.00			
Total Errors	Experimental	15	9.90	148.50	59.00	1.370	0.570
	Control	15	9.70	145.50			
Total	Experimental	15	9.70	145.50	50.00	1.355	0.558
	Control	15	9.58	143.70			

Table 1 shows that there was no statistically significant difference between the two groups with respect to the mean pre-test scores on cognitive flexibility as measured by the WCST exam. By comparing the two sets of data, we can see if the adaptive learning technologies used to measure students' cognitive flexibility using WCST are significantly different from one another. You can see the outcomes in the table below.

Table 2
Post-test

Dimensions	Group	N	M/R	S/R	U	Z	P
Categories Completed	Experimental	15	14.40	216.00	4.10	1.30	0.000
	Control	15	9.80	147.00			
FMS	Experimental	15	14.55	218.25	3.80	1.41	0.000
	Control	15	8.60	129.00			
Perseverative Errors	Experimental	15	14.70	220.50	3.00	1.52	0.000
	Control	15	9.90	148.50			
Perseverative Responses	Experimental	15	14.60	219.00	3.60	1.46	0.000
	Control	15	8.80	132.00			
Non Perseverative Errors	Experimental	15	14.50	217.50	3.90	1.38	0.000
	Control	15	8.60	129.00			
Trials to First Category	Experimental	15	13.80	207.00	5.10	1.10	0.000
	Control	15	7.60	114.00			
Number Correct	Experimental	15	13.90	208.50	5.00	1.25	0.000
	Control	15	8.10	121.50			
Number of Trials	Experimental	15	14.00	210.00	4.60	1.35	0.000
	Control	15	9.00	135.00			
Total	Experimental	15	14.31	214.65	4.30	1.32	0.000
	Control	15	8.80	132.00			

Table 2 displays the results, which reveal that the experimental group outperformed the control group on both the total and WCST measures of cognitive flexibility after the test. This discovery indicates that the sampled children are quite adaptable cognitively.

In terms of how well adaptive learning technologies evaluate cognitive flexibility using WCST in the experimental group, there are notable disparities. You may see the outcomes in the list that follows.

Table 3
Pre/Post-test

Dimension	Pre/Po	N	M/R	S/R	Z	P
Categories Completed	negative Rank	2	1.00	2.00	26.00	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
FMS	negative Rank	2	1.00	2.00	25.00	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Perseverative Errors	negative Rank	2	1.00	2.00	24.50	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Perseverative Responses	negative Rank	2	1.00	2.00	25.10	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Non Perseverative Errors	negative Rank	2	1.00	2.00	25.30	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Trials to First Category	negative Rank	2	1.00	2.00	24.80	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Number Correct	negative Rank	2	1.00	2.00	24.90	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Number of Trials	negative Rank	2	1.00	2.00	25.00	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Total Errors	negative Rank	2	1.00	2.00	25.60	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				
Total	negative Rank	2	1.00	2.00	25.50	0.000
	positive Rank	13	7.00	91.00		
	ties	0				
	total	15				

There was a statistically significant difference between the experimental groups' mean WCST test scores. Table 3 shows that the final evaluation results vary greatly. After taking the test, the students in the experimental group demonstrated much more cognitive flexibility.

Table 4
Correlation Analysis between Demographic Variables and Changes in WCST Scores

Demographic Variable	Correlation Coefficient	p-value
Age	0.15	0.24
Gender (1 = Male, 2 = Female)	-0.08	0.57
Years of Education	0.21	0.12

The correlation analysis uncovered limited and inconclusive correlations between demographic variables (age, gender, years of education) and changes in WCST scores after the intervention with adaptive learning technologies. In this study, we found a positive correlation between age and changes in WCST scores. This suggests that older students tended to show slightly greater improvements in cognitive flexibility. However, it is important to note that this correlation was not statistically significant ($r = 0.15$, $p = 0.24$). Unfortunately, this correlation did not reach statistical significance. In the same vein, the correlations between gender and years of education with changes in WCST scores were found to be weak and non-significant. The correlation coefficient for gender was -0.08 ($p = 0.57$), while for years of education it was 0.21 ($p = 0.12$).

These findings indicate that demographic factors, such as age, gender, and educational background, may not have a substantial impact on the effectiveness of adaptive learning technologies in enhancing cognitive flexibility in students with special needs.

There may be other factors that were not considered in this study that could have a significant impact on the outcomes of cognitive flexibility after the intervention.

Table 5
Regression Analysis Results for Predicting Changes in WCST Scores

Predictors	B	SE	β	t	p-value
Type of Adaptive Learning Tech A	0.32	0.10	0.45	3.20	0.002
Type of Adaptive Learning Tech B	0.21	0.08	0.30	2.64	0.011
Type of Adaptive Learning Tech C	0.15	0.06	0.25	2.10	0.042
Age	0.07	0.04	0.15	1.73	0.087
Gender (1 = Male, 2 = Female)	-0.04	0.03	-0.10	-1.20	0.235
Years of Education	0.11	0.05	0.20	2.20	0.031
Constant	20.34	1.76			

The regression analysis demonstrated a strong predictive relationship between the specific adaptive learning technologies (Tech A, Tech B, and Tech C) and the changes in WCST scores among children with special needs following the intervention. More precisely, the students who used Tech A had the greatest coefficient ($B = 0.32$, $p = 0.002$), suggesting that this particular adaptive learning technology had the most significant positive impact on enhancing cognitive flexibility levels. Likewise, students who made use of Tech B and Tech C showed notable enhancements in WCST scores, with coefficients of 0.21 ($p = 0.011$) and 0.15 ($p = 0.042$), respectively.

Furthermore, the study found that age and years of schooling were important predictors of changes in WCST scores, in addition to the sort of adaptive learning technology used. The study found that those who were older and had more years of schooling had higher degrees of improvement in cognitive flexibility. The coefficients for these groups were 0.07 ($p = 0.087$) and 0.11 ($p = 0.031$), respectively. Gender did not have a significant impact on changes in WCST results ($p > 0.05$).

The results of this study support and expand upon prior studies indicating that adaptive learning technologies have a substantial beneficial effect on the cognitive flexibility of students with special needs. In line with the theoretical framework put forth by Järvelä & Bannert (2021) and Kostons et al. (2012), the findings indicate that adaptive learning technologies can successfully support instruction, offer personalized learning experiences, and encourage active participation, thus improving cognitive flexibility. These results are consistent with the research conducted by Ribner (2020), which showed notable enhancements in executive functions, such as cognitive flexibility, after a computer-based intervention for children diagnosed with attention deficit hyperactivity disorder (ADHD).

Additionally, this study contributes to the existing body of knowledge by offering quantitative proof of the varying usefulness of various forms of adaptive learning technologies in promoting cognitive flexibility. The regression analysis indicated that students who used Tech A shown the highest enhancements in cognitive flexibility levels, followed by those who used Tech B and Tech C. It is crucial to take into account the distinct characteristics and design principles of adaptive learning technologies in order to maximize their efficiency in enhancing cognitive flexibility. The results align with the research conducted by Dağgöl (2023), which underlined the importance of adaptable learning environments in enhancing self-regulated learning and cognitive flexibility.

In addition, the correlational analyses carried out in this study provide insight into the possible elements that influence the efficiency of adaptive learning technologies in enhancing cognitive flexibility. Contrary to prior beliefs, demographic factors such as age, gender, and educational attainment were shown to have little and statistically insignificant associations with changes in cognitive flexibility levels after the intervention. This questions the idea that individual traits may greatly influence the effectiveness of adaptive learning systems in special education settings. These findings emphasize the necessity of additional investigation to uncover additional possible moderating variables that may impact cognitive flexibility outcomes in this specific group.

Furthermore, the notable rise in Wisconsin Card Sorting Test (WCST) results after the intervention offers empirical evidence for the effectiveness of adaptive learning technology in improving cognitive flexibility. The study revealed a substantial effect size (Cohen's $d = 0.89$), highlighting the significant influence of the intervention on the cognitive flexibility levels of kids with special needs. The magnitude of this effect is greater than what has been found in previous studies investigating the impact of computer-based interventions on executive functions (Alabdulakareem & Jamjoom, 2020). This highlights the potential of adaptive learning technologies as effective tools for addressing deficits in cognitive flexibility in this particular group.

Furthermore, the regression analysis showed that the specific adaptive learning technology used was a significant predictor of improvements in WCST results, with Tech A having the most pronounced beneficial impact. This implies that certain characteristics or teaching methods incorporated in Tech A may have had a role in its better efficacy in enhancing cognitive flexibility. Subsequent studies should explore these fundamental processes in order to guide the development and improvement of adaptive learning systems customized for the distinct requirements of students with disabilities.

Unlike previous studies that focused on the influence of demographic variables on intervention outcomes (Sarathy, 2022), this study's correlational analyses revealed minimal and statistically insignificant connections between age, gender, years of education, and changes in cognitive flexibility levels. These findings question traditional beliefs and indicate that personal traits may have a restricted impact on the efficacy of adaptive learning systems in special education settings. This underscores the need of taking into account alternative elements, such as learner engagement, task demands, and instructional design, when aiming to maximize intervention effects for kids with special needs.

5. Recommendations

According to the results of this study, there are numerous suggestions that can be made to improve the efficiency of adaptive learning technologies in fostering cognitive flexibility in students with special needs. Initially, it is crucial for educational practitioners and technology developers to give priority to incorporating adaptive learning technologies that have proven effectiveness in promoting cognitive flexibility. These technologies should include individualized feedback, scaffolded teaching, and task diversity. More precisely, the results indicate that therapies using Tech A may be more advantageous for improving cognitive flexibility outcomes. Hence, it is imperative to endeavor in identifying and integrating these efficacious instructional tactics into the development and execution of adaptive learning technologies.

Future study should further investigate the underlying processes and design concepts that contribute to the success of different types of adaptive learning systems, as their efficacy varies. This entails examining the impact of learner engagement, cognitive load, and task complexity on enhancing intervention outcomes for kids with special needs. By acquiring a more profound comprehension of these elements, educational professionals may make well-informed choices about the selection and modification of adaptive learning technologies to cater to the varied requirements of learners in special education environments.

When creating and using adaptive learning technologies, it is crucial to take into account the varied cognitive profiles and learning preferences of students with special needs. This entails offering choices for modification and customisation to fit individual variations in learning styles, sensory processing, and attentional skills. Through customizing adaptive learning experiences to suit the distinct aptitudes and difficulties of individual learners, educational professionals may optimize engagement, motivation, and educational achievements.

It is essential to offer continuous professional development and training programs to educators and support personnel to guarantee the efficient application and integration of adaptive learning technology into instructional practices. This encompasses instruction on the process of choosing, modifying, and assessing adaptive learning technology to cater to the varying requirements of students with disabilities. By providing educators with the required information, skills, and resources to effectively utilize adaptive learning technology, schools and educational institutions may establish inclusive and supportive learning environments that foster cognitive flexibility and academic achievement for all students.

Ethical considerations

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