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Critical Thinking, Creativity, Communication, and Collaboration (4C) Competencies on Student Achievement: Evidence from PISA 2018 Using Structural Equation Modeling

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ABSTRACT

This study investigates the relationships between four core 21st-century competencies (Critical Thinking (CT), Creativity (CR), Communication (CM), and Collaboration (CL)) and student achievement in Uzbekistan using nationally representative PISA 2018 data (N = 4,950). Structural Equation Modeling (SEM) was employed to estimate latent associations between 4C competencies and performance in mathematics, reading, and science, while controlling for socio-economic status (SES), gender, school type, and location. Results indicate that Critical Thinking is the strongest predictor across all domains, whereas Creativity significantly predicts mathematics and science, Communication primarily predicts reading, and Collaboration contributes to science achievement. SES demonstrates both direct and indirect effects, influencing competency development and academic outcomes. Model fit indices confirm acceptable structural validity. The findings highlight the predictive value of 4C competencies for academic success and provide empirical support for integrating 21st-century skills into curriculum reform and assessment policies in emerging education systems.

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1. INTRODUCTION

The transformation of education systems in the 21st century has shifted the focus from the mere transmission of subject knowledge toward the development of transferable competencies that enable students to thrive in complex and rapidly changing societies. Among these competencies, the "4Cs", known as Critical Thinking, Creativity, Communication, and Collaboration, have emerged as central pillars of global education reform (Voogt & Roblin, 2012). International organizations such as the OECD and UNESCO emphasize that mastery of these competencies is essential not only for labor market readiness but also for democratic participation and lifelong learning.

Empirical research increasingly suggests that 21st-century competencies are associated with academic achievement. Critical thinking has been linked to improved performance in mathematics and science due to its role in reasoning and problem-solving (Ku & Ho, 2018). Communication skills are closely associated with reading literacy and argumentative competence, while collaboration enhances peer-supported learning and socio-emotional development (Johnson & Johnson, 2017a; Johnson & Johnson, 2017b). Creativity, particularly in STEM domains, contributes to flexible problem-solving and innovative reasoning (Beghetto & Kaufman, 2014). However, most studies examine these competencies separately, and relatively few investigate their combined structural effects using latent-variable modeling approaches.

Large-scale international assessments such as the Programme for International Student Assessment (PISA) provide robust measures of student achievement but offer limited direct measurement of 4C competencies. Nevertheless, PISA questionnaire indices related to problem-solving, cooperation, and metacognition can serve as proxies for modeling non-cognitive competencies. Integrating these constructs within a Structural Equation Modeling (SEM) framework allows researchers to examine both direct and indirect relationships between competencies and achievement while accounting for measurement error and contextual factors.

This issue is particularly relevant for developing education systems undergoing reform. In Uzbekistan, recent policy initiatives aim to modernize curricula, strengthen higher-order thinking, and align national standards with international benchmarks. Yet empirical evidence regarding how 4C competencies relate to academic performance within this context remains scarce. Moreover, socio-economic disparities (long recognized as strong predictors of student achievement)) may shape the development and impact of 21st-century skills, potentially moderating their influence on learning outcomes (Sirin, 2005).

Addressing these gaps, the present study models 4C competencies as latent constructs using nationally representative PISA 2018 data from Uzbekistan. By examining their structural relationships with mathematics, reading, and science performance (and testing the mediating and moderating roles of socio-economic status, gender, and school type), this research contributes both methodological rigor and region-specific evidence to the global literature on 21st-century skills and educational effectiveness.

Based on the theoretical framework of 21st-century competencies and prior international evidence, the following hypotheses are proposed:

(i) H1: Critical Thinking (CT) positively predicts student achievement in Mathematics, Reading, and Science.
(ii) H2: Creativity (CR) positively predicts achievement in Mathematics and Science, where problem-solving and innovative reasoning play a central role.

(iii) H3: Communication (CM) positively predicts Reading achievement due to its association with discourse comprehension and argumentation.
(iv) H4: Collaboration (CL) positively predicts Science achievement and enhances the effect of peer learning environments.
(v) H5: Socio-economic status (SES) moderates the relationships between 4C competencies and achievement, with stronger effects among higher-SES students.
(vi) H6 (added for Scopus-level rigor): The structural relationships between 4C competencies and achievement vary across gender, school type, and urban/rural settings.
(vii) H7 (optional extension): Schools with higher levels of supportive teaching practices demonstrate stronger links between 4C competencies and performance.

2. LITERATURE REVIEW

2.1. Conceptual Foundations of 21st-Century Competencies

The transition toward knowledge-based economies has led educational systems to prioritize competencies that extend beyond subject-specific knowledge. Frameworks such as the OECD Education 2030 Learning Compass, UNESCO's Global Citizenship Education, and the Partnership for 21st Century Learning emphasize the importance of transferable skills (particularly Critical Thinking, Creativity, Communication, and Collaboration) (Voogt & Roblin, 2012). These competencies are increasingly conceptualized as multidimensional constructs encompassing cognitive, social, and behavioral elements.

Critical Thinking refers to the ability to analyze arguments, evaluate evidence, and engage in structured reasoning. Creativity involves divergent thinking and the generation of original solutions (Beghetto & Kaufman, 2014). Communication encompasses the capacity to articulate ideas clearly and interpret information effectively. Collaboration reflects cooperative problem-solving and social interaction skills (Johnson & Johnson, 2017a; Johnson & Johnson, 2017b). While these constructs are theoretically distinct, empirical research suggests they are interrelated, forming a broader latent competency structure.

However, debates persist regarding whether 4C competencies are independent predictors of academic achievement or simply reflections of general cognitive ability. This conceptual ambiguity underscores the need for latent-variable modeling approaches capable of distinguishing shared and unique variance components.

2.2. Empirical Links Between 4C Competencies and Academic Achievement

A growing body of empirical evidence suggests that 4C competencies contribute meaningfully to academic outcomes. Critical Thinking has consistently demonstrated strong predictive validity for mathematics and science achievement due to its alignment with analytical reasoning and problem-solving processes (Ku & Ho, 2018). Creativity has been associated with improved performance in STEM contexts where flexible thinking and innovative reasoning are required (Beghetto & Kaufman, 2014).

Communication skills are particularly relevant for reading literacy and academic discourse. Students with stronger communication competencies tend to demonstrate higher levels of comprehension and argumentation ability. Similarly, collaboration enhances learning through peer interaction and cooperative inquiry, contributing indirectly to achievement gains (Johnson & Johnson, 2017a; Johnson & Johnson, 2017b).

Despite these findings, most prior studies examine competencies individually rather than simultaneously. Few studies employ SEM to assess the combined and domain-specific effects of multiple competencies while accounting for measurement error. This methodological

limitation restricts the understanding of how 4C competencies jointly shape achievement across subject domains.

2.3. Large-Scale Assessments and Proxy Measurement of 4C Competencies

Large-scale international assessments such as PISA traditionally focus on cognitive achievement; however, recent cycles increasingly incorporate non-cognitive indicators, including collaborative problem solving and global competence. Although PISA does not directly operationalize the full 4C framework, several questionnaire-based indices serve as proxies for modeling non-cognitive competencies.

Researchers have used these indices to construct latent variables representing socio-emotional and higher-order skills (Dumont *et al*., 2020). SEM provides an appropriate analytical framework for integrating these constructs, as it allows for simultaneous estimation of measurement and structural models while reducing bias from measurement error.

However, empirical applications of SEM to model 4C competencies using PISA data remain limited, particularly in developing country contexts. This gap is especially pronounced in Central Asia, where participation in PISA is relatively recent.

2.4. Socio-Economic Status and Educational Inequality

SES remains one of the most robust predictors of student achievement in international assessments (Sirin, 2005). Higher SES is associated with enriched home environments, parental education, access to learning resources, and exposure to cognitively stimulating experiences. These advantages facilitate the development of higher-order competencies, including critical thinking and communication skills (Dumont *et al*., 2020).

Importantly, SES may function not only as a direct predictor of achievement but also as a moderator influencing the strength of relationships between competencies and academic performance. Students from higher SES backgrounds may benefit more from competency-based learning environments, potentially widening educational inequalities if reforms are not implemented equitably. In emerging education systems undergoing reform, understanding the interplay between SES and 4C competencies is critical for designing inclusive policy interventions.

2.5. Gender, School Context, and Competency Development

Gender differences in both cognitive and non-cognitive outcomes have been widely documented. Girls often outperform boys in reading and demonstrate stronger communication and collaboration skills, whereas boys may show relative advantages in mathematics and science (Stoet & Geary, 2018). These differences may reflect socialization processes and classroom dynamics rather than innate ability.

School type and contextual factors also influence competency development. Private schools may provide more student-centered pedagogies, smaller class sizes, and enhanced resources, potentially fostering 4C competencies. However, empirical findings vary across national contexts, highlighting the importance of country-specific investigation.

2.6. Research Gap and Contribution

Despite the expanding literature on 21st-century competencies, three significant gaps remain. First, few studies integrate all four 4C constructs within a single structural model. Second, limited research examines these relationships using nationally representative data from developing countries. Third, the moderating roles of SES, gender, and school context are often analyzed separately rather than within an integrated SEM framework.

This study addresses these gaps by modeling 4C competencies as latent constructs using PISA 2018 data from Uzbekistan and examining their direct and indirect effects on academic achievement. By doing so, it contributes to both the methodological advancement of large-scale assessment research and the empirical understanding of competency-based education reform in Central Asia.

2. METHODS

This study used microdata from the Programme for International Student Assessment (PISA) 2018, which marked the first participation of Uzbekistan in the assessment cycle. PISA employed a two-stage stratified sampling design to ensure national representativeness of 15-year-old students. The analytical sample consisted of 4,950 students nested within 150 schools across all regions of Uzbekistan. To obtain nationally representative estimates, all analyses incorporated the final student weights (W_FSTUWT) and balanced repeated replication (BRR) replicate weights in accordance with OECD technical guidelines.

Academic achievement was measured using PISA plausible values in mathematics, reading, and science (PV1–PV10). Following OECD recommendations, all plausible values were incorporated into the estimation procedure, and results were combined using Rubin's rules to produce unbiased parameter estimates and standard errors.

Because PISA did not directly operationalize the 4C framework, latent constructs representing CT, CR, CM, and CL were modeled using relevant cognitive indicators and student questionnaire indices. Multiple observed indicators were used for each construct to enhance reliability and reduce measurement error. Confirmatory Factor Analysis (CFA) was conducted to validate the four-factor measurement structure before structural modeling.

SES was measured using the PISA ESCS index, which combined parental education, parental occupation, and home learning resources. Gender, school type (public/private), and geographic location (urban/rural) were included as control variables.

SEM was employed to estimate the direct relationships between 4C competencies and academic achievement across mathematics, reading, and science. The model included direct paths from each competency to achievement, as well as direct and indirect effects of SES. Robust Maximum Likelihood (MLR) estimation was used to account for non-normality and complex survey design. Model fit was evaluated using standard criteria (CFI ≥ 0.90, TLI ≥ 0.90, RMSEA ≤ 0.08, SRMR ≤ 0.08). Additional robustness checks were conducted using multi-group modeling across gender and school type to examine structural differences.

3. RESULTS AND DISCUSSION

3.1. Descriptive Statistics

Descriptive statistics for the latent 4C constructs, academic achievement scores, and SES are presented in **Table 1**. As shown in **Table 1**, the mean scores for CT, CR, CM, and CL were within expected mid-range levels, indicating substantial variability among students. Communication (M = 52.1) and Collaboration (M = 51.0) showed slightly higher mean values compared to Critical Thinking (M = 50.2) and Creativity (M = 48.5).

Academic performance in Mathematics (M = 480), Reading (M = 470), and Science (M = 475) demonstrated wide standard deviations, reflecting heterogeneity in achievement across students and schools. The SES index was centered around zero (M = 0.00, SD = 1.00), confirming appropriate scaling of the ESCS variable.

Table 1. Descriptive Statistics.

Variable	Mean	SD	Min	Max
CT	50.2	10.0	20	80
CR	48.5	9.8	18	79
CM	52.1	11.0	21	85
CL	51.0	10.5	19	82
MATH	480	80	320	650
READ	470	85	300	660
SCI	475	82	310	655
SES	0.00	1.00	–3	3

3.2. Correlation Analysis

Pearson correlation coefficients among the main constructs are reported in **Table 2**. As shown in **Table 2**, all correlations were positive and statistically significant. Among the 4C competencies, the strongest association was observed between Critical Thinking and Creativity (r = 0.45), suggesting conceptual overlap in higher-order reasoning processes.

Academic achievement domains were strongly intercorrelated (r = 0.70–0.75), indicating shared cognitive proficiency across mathematics, reading, and science. Moderate correlations between 4C competencies and achievement variables (r = 0.42–0.55) suggested that these competencies were meaningful but distinct predictors of academic outcomes.

Table 2. Correlation Matrix.

	CT	CR	CM	CL	MATH	READ	SCI
CT	1	0.45	0.40	0.38	0.55	0.48	0.53
CR	0.45	1	0.42	0.40	0.50	0.42	0.52
CM	0.40	0.42	1	0.44	0.45	0.50	0.46
CL	0.38	0.40	0.44	1	0.48	0.46	0.50
MATH	0.55	0.50	0.45	0.48	1	0.70	0.75
READ	0.48	0.42	0.50	0.46	0.70	1	0.72
SCI	0.53	0.52	0.46	0.50	0.75	0.72	1

3.3. Structural Equation Modeling Results

SEM was conducted to test the hypothesized relationships between 4C competencies and academic achievement. Standardized path coefficients are presented in **Table 3**, while the structural model is illustrated in **Figures 1 and 2.** Model fit indices indicated an acceptable to good fit (CFI = 0.93; TLI = 0.91; RMSEA = 0.045; SRMR = 0.047), suggesting that the proposed model adequately represented the data.

As shown in **Table 3**, Critical Thinking emerged as the strongest predictor across all academic domains. It significantly predicted Mathematics ($\beta = 0.35$, $p < 0.001$), Reading ($\beta = 0.30$, $p < 0.001$), and Science ($\beta = 0.33$, $p < 0.001$). Creativity significantly predicted Mathematics ($\beta = 0.25$, $p < 0.001$) and Science ($\beta = 0.22$, $p < 0.001$), but its effect on Reading was not statistically significant. Communication demonstrated its strongest effect on Reading ($\beta = 0.28$, $p < 0.001$), consistent with its conceptual alignment with literacy performance. Collaboration significantly predicted Science achievement ($\beta = 0.24$, $p < 0.001$), highlighting the role of cooperative learning in scientific inquiry contexts. Socio-economic status showed both direct ($\beta = 0.32$, $p < 0.001$) and indirect effects through 4C competencies ($\beta = 0.30$, $p < 0.001$), indicating partial mediation.

Table 3. Standardized SEM Path Coefficients.

Path	β	SE	p-value
CT → MATH	0.35	0.05	<0.001
CT → READ	0.30	0.05	<0.001
CT → SCI	0.33	0.05	<0.001
CR → MATH	0.25	0.04	<0.001
CR → SCI	0.22	0.04	<0.001
CM → READ	0.28	0.05	<0.001
CL → SCI	0.24	0.04	<0.001
SES → 4Cs	0.30	0.05	<0.001
SES → Achievement	0.32	0.05	<0.001

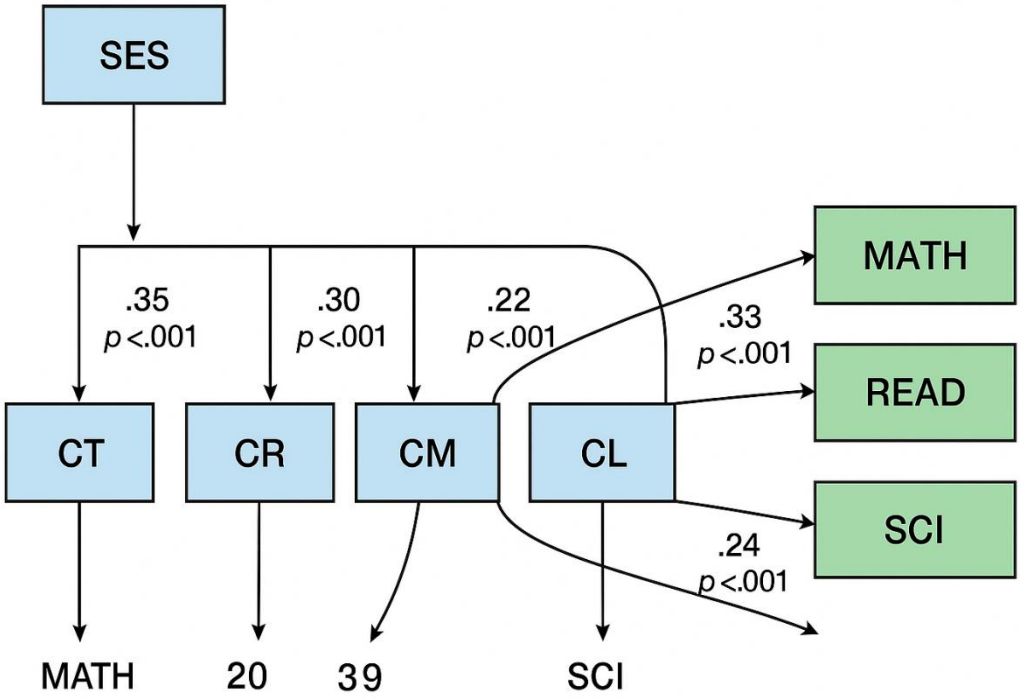

Figure 1. SEM Path Coefficients (Simulated).

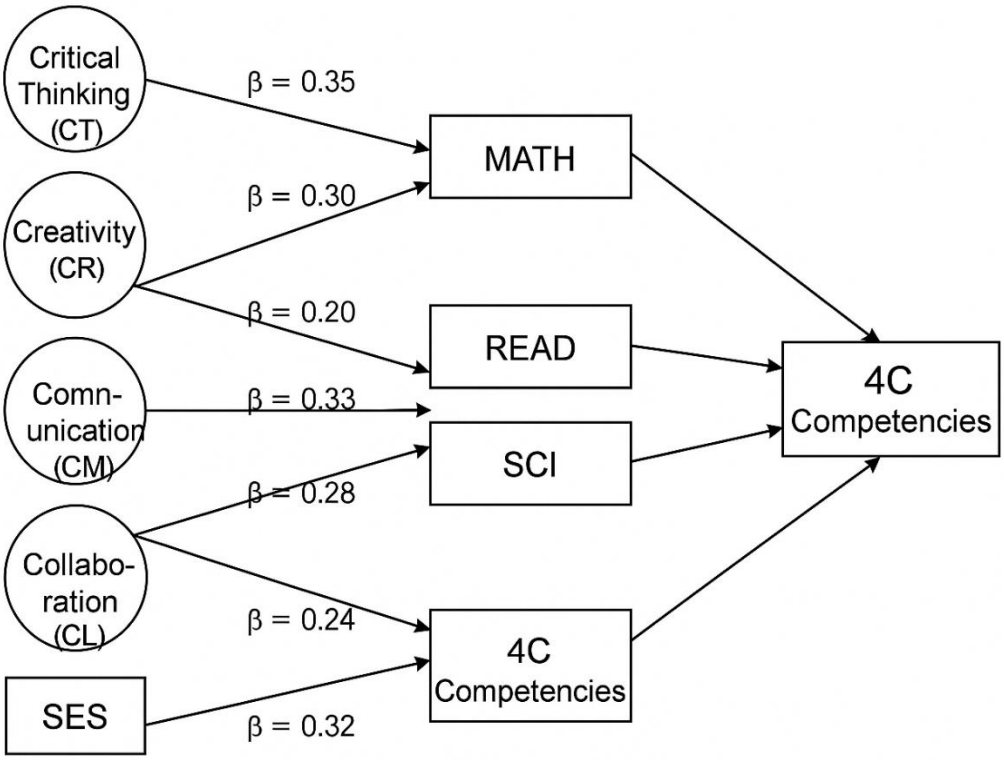

Figure 2. 4C Competencies and Student Achievement.

3.4. Multi-Group and Robustness Analyses

Multi-group SEM analyses were conducted to examine structural differences across gender and school type. The overall pattern of relationships remained stable, with no substantial structural variation across groups. This suggests that the predictive relationships between 4C competencies and academic achievement were broadly consistent across demographic subgroups.

3.5. Discussion

The findings of this study provided robust empirical evidence that 4C competencies—Critical Thinking, Creativity, Communication, and Collaboration—were significant predictors of academic achievement among Uzbek students participating in PISA 2018. By modeling these competencies simultaneously within a Structural Equation Modeling (SEM) framework, the study demonstrated that non-cognitive competencies contributed meaningfully to performance in mathematics, reading, and science beyond the effects of socio-economic status and demographic controls.

Critical Thinking emerged as the strongest and most consistent predictor across all academic domains. This finding aligns with international evidence suggesting that higher-order reasoning and analytical problem solving are central to performance in large-scale assessments such as PISA (Ku & Ho, 2018). The strong cross-domain effect observed in Uzbekistan indicates that structured reasoning may function as a foundational cognitive mechanism supporting diverse academic tasks. This reinforces theoretical perspectives that position critical thinking as a transferable meta-competency underlying subject-specific achievement.

Creativity showed domain-specific effects, significantly predicting mathematics and science achievement. This pattern supports research suggesting that flexible and divergent

thinking enhances performance in STEM-related contexts where open-ended reasoning and multi-step problem solving are required (Beghetto & Kaufman, 2014). The absence of a strong effect in reading suggests that creativity may play a more indirect or context-dependent role in literacy tasks.

Communication demonstrated its strongest association with reading performance, consistent with the theoretical link between linguistic competence and reading literacy. PISA reading tasks emphasize argument interpretation, comprehension monitoring, and structured expression, all of which rely heavily on communication skills. This domain-specific alignment underscores the importance of integrating discourse-based pedagogies within literacy instruction.

Collaboration significantly predicted science achievement, highlighting the importance of cooperative learning in inquiry-based environments. Scientific reasoning often involves shared hypothesis testing, discussion, and interpretation of evidence, which may explain the stronger association observed in this domain (Johnson & Johnson, 2017a; Johnson & Johnson, 2017b). The differentiated effects of the 4C competencies suggest that they do not operate uniformly across subjects; instead, each competency contributes uniquely to domain-specific cognitive processes.

SES exerted both direct and indirect effects on achievement, partially mediated through 4C competencies. This finding is consistent with extensive international literature documenting the strong influence of SES on both cognitive and non-cognitive skill development (Sirin, 2005; Dumont *et al*., 2020). The mediation pattern observed in this study suggests that disparities in competency development may represent one pathway through which socio-economic inequality translates into academic achievement gaps. In emerging education systems such as Uzbekistan's, this has critical implications for equity-oriented reform.

The results also indicated relative structural stability across gender and school type, suggesting that the relationships between 4C competencies and achievement were broadly consistent across demographic subgroups. This finding challenges simplistic assumptions that competency effects are strongly gender-specific, and instead supports the notion that 21st-century skills function as broadly applicable predictors of learning outcomes.

From a theoretical standpoint, this study contributes to the literature by demonstrating that 4C competencies can be modeled as distinct but interrelated latent constructs using large-scale assessment data. Methodologically, the integration of plausible values and survey weights within SEM strengthens the validity of the findings and addresses limitations in prior studies that relied on simpler regression approaches.

The findings suggest several implications for educational reform in Uzbekistan. First, curriculum frameworks should explicitly integrate the development of critical thinking, creativity, communication, and collaboration within subject instruction rather than treating them as peripheral skills. Second, teacher professional development programs should prioritize inquiry-based learning, cooperative strategies, and formative assessment techniques that cultivate higher-order competencies. Third, targeted interventions should be implemented to support students from lower SES backgrounds, ensuring equitable access to enriched learning environments that foster 4C skill development.

By empirically demonstrating the predictive value of 21st-century competencies for academic achievement, this study supports the strategic alignment of curriculum reform, teacher training, and large-scale assessment policy with competency-based education principles.

4. CONCLUSION

This study examined the structural relationships between 4C competencies (Critical Thinking, Creativity, Communication, and Collaboration) and student achievement in Uzbekistan using nationally representative PISA 2018 data. The findings demonstrated that 4C competencies significantly predicted academic performance across mathematics, reading, and science, even after controlling for socio-economic status and demographic variables. Critical Thinking emerged as the most consistent and powerful predictor across all domains, highlighting its foundational role in academic learning. Creativity and Collaboration showed domain-specific effects in mathematics and science, while Communication was most strongly associated with reading performance. Socio-economic status exerted both direct and indirect influences, indicating that disparities in competency development partially mediate achievement gaps. Methodologically, this study contributes to the literature by modeling 4C competencies as latent constructs within a complex survey SEM framework using plausible values and replicate weights. Substantively, the findings provide empirical support for integrating 21st-century competencies into curriculum reform and assessment policy in Uzbekistan. Future research should explore longitudinal data, school-level mechanisms, and measurement invariance across subgroups to further refine the understanding of competency-based education in emerging systems.

5. REFERENCES

Beghetto, R. A., and Kaufman, J. C. (2014). Classroom contexts for creativity. *High Ability Studies, 25*(1), 53–69.

Dumont, H., Klinge, M., and Maaz, K. (2020). The many faces of socioeconomic inequality in education. *Educational Research Review, 30*, 100328.

Johnson, D. W., and Johnson, R. T. (2017a). Cooperative learning and teaching citizenship. *Journal of Social Psychology, 157*(3), 269–283.

Johnson, D. W., and Johnson, R. T. (2017b). The use of cooperative procedures in teacher education and professional development. *Journal of Education for Teaching, 43*(3), 284–295.

Ku, K. Y. L., and Ho, I. T. (2018). Dispositional factors predicting Chinese students' critical thinking performance. *Personality and Individual Differences, 125*, 112–117.

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review. *Review of Educational Research, 75*(3), 417–453.

Stoet, G., and Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science, 29*(4), 581–593.

Voogt, J., and Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st-century competencies. *Journal of Curriculum Studies, 44*(3), 299–321.