

A multi-group structural equation modelling analysis for the impact of digital art on critical thinking across language contexts

Gulvira Togabayeva¹, Rabilova Zoya¹, Miyat Janayev¹, Gulnar Shaizadanova², Anarbek Kozybay¹

¹Department of Art Education, Faculty of Arts, Abai Kazakh National Pedagogical University, Almaty, Kazakhstan

²Department of Graphic and Fashion Design, International Education Corporation, Almaty, Kazakhstan

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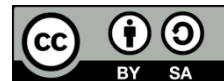
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ABSTRACT

This study investigates the structural relationships among creativity (Crtvt), technological adaptability (TchAd), problem solving (PrblS), analytical thinking (Anlyt), and self-reflection (SlfRf) in the context of digital art education. A total of 249 students from three higher education institutions in Kazakhstan participated in the study. Using a 25-item Likert-scale instrument, data were collected from students instructed in either Kazakh or Russian. Structural equation modeling (SEM) with multi-group analysis was employed to test a theoretically grounded model of critical thinking development through digital art. The results revealed that Crtvt and TchAd significantly predicted students' problem-solving abilities, which in turn emerged as the strongest predictor of both Anlyt and SlfRf. Crtvt also had moderate direct effects on these higher-order thinking outcomes, while TchAd showed a stronger influence on PrblS and SlfRf than on Anlyt. Multi-group analysis indicated that the measurement and structural models were invariant across language groups.

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Corresponding Author:

Gulvira Togabayeva

Department of Art Education, Faculty of Arts, Abai Kazakh National Pedagogical University

Almaty, Kazakhstan

Email: togabaevagulvira17@gmail.com

1. INTRODUCTION

Digital art tools like Adobe Photoshop, Procreate, and virtual reality platforms have become a cornerstone of modern art education, reflecting the broader integration of technology into learning environments [1]. As students increasingly engage with these tools, educators and researchers try to understand their impact on cognitive development, particularly critical thinking skills such as analysis, problem-solving, and evaluation. Traditional art practices have long been recognized for improving these skills [2], yet the distinct features of digital art, such as interactivity and rapid iteration, raise questions about its unique contributions.

This gap in knowledge indicates the need for investigation, especially as educational systems adapt to a digital age where critical thinking and digital literacy are essential. Understanding digital art's effects could inform art curricula, improve teaching strategies, and equip student artists with skills for both creative and intellectual success. Thus, the purpose of this study is to investigate the structural relationships among creativity (Crtvt), technological adaptability (TchAd), problem solving (PrblS), analytical thinking (Anlyt), and self-reflection (SlfRf) in the context of digital art education. To guide this exploration, the study addresses four research questions:

- What are the structural relationships among Crtvt, TchAd, PrbIS, Anlyt, and SlfRf in the context of digital art education? (RQ1)
- To what extent do Crtvt and TchAd predict students' PrbIS, Anlyt, and SlfRf skills? (RQ2)
- Does PrbIS mediate the relationship between Crtvt/TchAd and students' critical thinking outcomes (Anlyt and SlfRf)? (RQ3)
- How does instructional language influence the relationships among cognitive and metacognitive learning variables? (RQ4)

2. LITERATURE REVIEW

Digital art, defined as creative work produced or modified using digital technologies, has become a significant medium in both artistic practice and education [3]. Unlike traditional art, which relies on physical materials like paint or charcoal, digital art employs software and hardware to create works ranging from illustrations to immersive virtual environments [4]. Its evolution began in the mid-20th century with pioneers like John Whitney using computers for animation, but it gained prominence in the 1990s with accessible tools like Adobe Photoshop, marking a shift toward widespread adoption [5]. Today, digital art encompasses diverse forms, including 2D graphics, 3D modeling, and interactive media, driven by technological advancements [6].

Current trends and technologies in digital art indicate its educational significance. Software like Adobe Creative Suite, Procreate, and Blender has become standard in classrooms, offering versatile platforms for creation [7]. Graphic tablets, such as those from Wacom, bridge traditional drawing techniques with digital precision, enhancing student engagement [8]. Moreover, emerging technologies like virtual reality and augmented reality are transforming art education by enabling students to interact with three-dimensional spaces and simulations, a trend noted in recent educational studies [9].

2.1. The role of art in developing critical thinking

Historically, art has been recognized as a powerful medium for cultivating critical thinking, with traditional practices laying the groundwork for its cognitive benefits. Dating back to the Renaissance, artists like Leonardo da Vinci exemplified how observation, experimentation, and reflection, hallmarks of critical thought, were integral to artistic mastery [10]. This perspective persisted into modern education, where art was valued not only for the aesthetic expression but also for its capacity to sharpen intellectual skills. Dewey [11], a foundational figure in educational theory, argued that artistic engagement involves active inquiry and problem-solving, processes that mirror critical thinking. These historical views show the longstanding belief that art is a disciplined practice requiring analysis and judgment, rather than a purely emotional endeavor.

The cognitive processes involved in artistic creation further illustrate its role in increasing critical thinking. Creating art demands problem-solving, as artists must navigate technical challenges, such as selecting media or resolving compositional issues [2]. Reflection is equally central, with artists continually assessing their work against personal or external standards, a process akin to evaluative thinking in Bloom's taxonomy. For instance, sketching a still life requires observing details, hypothesizing spatial relationships, and adjusting techniques, steps that engage analytical and synthetic skills. Sheridan *et al.* [2] identify these habits of mind, including "observe", "envision", and "reflect", as outcomes of studio art practice, suggesting that traditional art inherently builds cognitive capacities tied to critical thinking.

Empirical studies reinforce the link between art education and enhanced analytical and interpretive skills. Burton *et al.* [12] conducted a longitudinal study of elementary students, finding that those exposed to integrated arts curricula demonstrated significant gains in critical thinking, as measured by tasks requiring inference and interpretation, compared to peers without such exposure. Similarly, Winner and Hetland [13] reviewed evidence suggesting that art education strengthens students' abilities to analyze visual information and articulate reasoned critiques, skills transferable to other domains like science or literature.

2.2. Digital art vs. traditional art

Digital art and traditional art differ fundamentally in their tools, techniques, and creative processes, shaping distinct experiences for artists. Traditional art relies on physical media, such as pencils, paint, or clay, requiring manual skill and direct interaction with materials [14]. In contrast, digital art utilizes software (e.g., Adobe Photoshop and Procreate) and hardware (e.g., graphic tablets and computers), enabling artists to manipulate virtual canvases with tools like layers, undo functions, and filters [4]. These differences extend to technique: traditional methods demand precision in single attempts, while digital processes allow rapid iteration and experimentation [5]. The creative process also diverges, with traditional art often emphasizing tactile engagement and digital art prioritizing flexibility and technological integration, altering how artists approach composition and revision [15].

Research exploring how these differences influence cognitive skills suggests varied impacts on critical thinking and related abilities. Sheridan *et al.* [2] argue that traditional art improves observational and reflective skills through its slower, deliberate pace, engaging artists in sustained problem-solving. Conversely, digital art's immediacy, such as real-time adjustments or algorithmic assistance, may enhance divergent thinking and adaptability, as noted by Pepler [8], who found that digital media encourage students to explore multiple solutions quickly. However, studies are mixed: Burton *et al.* [12] observed that traditional art's physicality deepened analytical skills in young learners, while digital tools sometimes risked superficial engagement if over-relied upon. These findings indicate that the medium itself shapes the cognitive demands placed on artists, with implications for critical thinking development.

2.3. Impact of technology on student learning and creativity

The integration of digital technology into education has significantly influenced student learning, particularly in terms of engagement and motivation [16]. Digital tools, such as interactive software and multimedia platforms, enhance student interest by offering dynamic, visually rich environments that traditional methods often lack [17]–[19]. Research by Mishra and Koehler [20] highlights how technology, when paired with pedagogical strategies (e.g., the TPACK framework), increases student participation by making tasks more accessible and relevant, such as through gamified learning or collaborative online projects. In art education specifically, Pepler [8] found that digital media—like graphic design software—boosted motivation among students by connecting their creative efforts to real-world applications, increasing a sense of agency and purpose in their learning.

Evidence also points to technology's role in improving Crtvt and innovation within educational contexts. Digital tools enable students to experiment with ideas rapidly, a key driver of creative thinking [21]. For instance, software allowing infinite iterations, such as Blender for 3D modeling, encourages risk-taking and divergent thought, as students can explore without fear of permanent mistakes [22]. Craft [23] further demonstrates that technology-rich environments, including virtual reality and digital storytelling, stimulate innovation by providing novel ways to conceptualize and present ideas. In art classrooms, this translates to students producing work that blends traditional aesthetics with cutting-edge techniques, expanding their creative repertoires [8].

2.4. Empirical studies on digital art and critical thinking

Empirical research examining the impact of digital art on critical thinking has begun to emerge, though it remains a relatively underexplored area within art education. Pepler [8] conducted a qualitative study of youth engaging in digital media arts, finding that activities like digital video production enhanced critical thinking skills such as analysis and synthesis, as participants navigated complex narrative structures and technical challenges. Similarly, Henriksen *et al.* [22] investigated the use of digital tools in creative education, reporting that students using software like Adobe Creative Suite demonstrated improved problem-solving and evaluative skills, measured through teacher observations and student reflections.

Despite these evaluations, significant gaps persist in the literature, particularly regarding student artists and specific age groups. Much of the existing research, such as that by Mishra and Koehler [20], explores technology's broader educational impact (e.g., via the TPACK framework) without isolating digital art's effects on critical thinking among art students. Burton *et al.* [12] examined arts integration's influence on cognition, including critical thinking, but their study focused on traditional media and elementary students, leaving questions about digital art and older learners, such as secondary or college-level student artists, unanswered. Furthermore, Henriksen *et al.* [21] notes that while technology enhances Crtvt, few studies specifically link digital art tools to critical thinking outcomes in art education, indicating a need for research on this population and skill set. This gap is critical, as student artists may engage with digital tools differently due to their artistic training and developmental stages.

2.5. Theoretical models linking digital art to cognitive development

Several theoretical models provide a lens through which to understand how digital art might enhance critical thinking and broader cognitive development among student artists. Constructivism, rooted in the work of Piaget and Vygotsky, posits that learning occurs through active construction of knowledge, a process well-suited to digital art's hands-on, exploratory nature [24]. In this framework, students using digital tools, like Adobe Illustrator or virtual reality platforms, build understanding by experimenting with visual concepts, aligning with critical thinking skills such as analysis and synthesis. Another relevant model, media richness theory Daft and Lengel [25] suggests that media with greater interactivity and sensory depth (e.g., digital art software) facilitate richer cognitive engagement than less dynamic tools, potentially amplifying students' ability to evaluate and refine their work.

The role of interactivity, iteration, and feedback in digital art processes is central to these models' explanatory power. Interactivity, a hallmark of digital tools, allows students to manipulate variables (e.g., color, form) in real time, improving problem-solving and decision-making [22]. Iteration, enabled by features like undo functions or layering, encourages repeated experimentation, where students refine their critical judgments through trial and error. Feedback, whether from software (e.g., visual previews) or peers in digital collaboration, provides immediate input that sharpens evaluative skills.

3. METHOD

3.1. Sample and context

This study involved a total of 249 students enrolled in visual arts and design programs at three higher education institutions in Kazakhstan. These institutions were selected due to their well-established programs in fine arts, design, and vocational education, and their integration of digital art practices into their curricula. Students were drawn from a wide range of academic levels and specializations, including graphic design, textile and fashion design, art pedagogy, visual arts, and digital media arts. The sample was diverse in terms of language of instruction, educational level, grade level, gender, and age. In terms of language background, 63% of the participants received instruction in Kazakh (n=156), while 37% were in the Russian instruction group (n=93). The gender distribution was predominantly female (89%), reflecting the demographics of art and education programs in the region, while male students comprised 11% of the sample. Participants' ages ranged from under 18 to over 30, with 50% under 18, 33% between 18–24 years, and 16% between 25–34 years. Grade levels varied, with 39% in Grade 1, 18% in Grade 2, 26% in Grade 3, and 17% in Grade 4. Students at Almaty Technological University and Abai Kazakh National Pedagogical University were primarily enrolled in professional and design-oriented programs such as graphic design, painting, and textile design, offered in both Kazakh and Russian. Kazakh State Women's Teacher Training University provided a unique context, as students were trained not only in fine arts but also in teaching methodologies and creative development, often linked to national educational reforms and gender-inclusive pedagogical strategies.

3.2. Instrument

To investigate the relationships among Crtvt, TchAd, PrblS, Anlyt, and SlfRf in the context of digital art education, a 25-item Likert-scale questionnaire, including demographic questions concerning language of instruction, gender, age group, grade level, and education level, was developed. The instrument was designed to measure five latent constructs central to critical thinking development in creative digital practices. Each construct was assessed using five items, developed by authors. Respondents rated each item on a 5-point Likert scale, ranging from 1=strongly disagree to 5=strongly agree. The items were reviewed by a panel of experts in art education, educational psychology, and educational measurement to ensure content validity. Pilot testing was conducted with three students to confirm clarity and appropriateness of language. Based on feedback, minor revisions were made to improve item comprehensibility. To accommodate the bilingual context of Kazakhstan, the questionnaire was made available in both Kazakh and Russian. Authors are fluent in both Kazakh and Russian. Items were concurrently translated from Kazakh to Russian during the development phase. In the final analysis, reliability tests (ordinal Cronbach's alpha, McDonald's omega, and average variance extracted (AVE)), confirmed that the instrument demonstrated strong construct validity and internal consistency for each of the five latent variables across both language groups.

3.3. Data collection

The data collection was conducted in February 2025 across three higher education institutions in Kazakhstan. Participation was voluntary, and students were informed about the purpose and confidentiality of the study prior to responding. A total of 303 students completed the questionnaire, of whom 249 provided complete and analyzable responses. The questionnaires were administered online through a Google Forms. Related link was shared with students during class time. It was also sent to students' emails for those were absent during class time.

3.4. Data analysis

Data were analyzed using structural equation modeling (SEM). The analysis was conducted in Jamovi using the lavaan SEM engine with the diagonally weighted least squares estimation method, appropriate for ordinal Likert-scale data. Following the validation of the measurement model, structural paths were specified among the five latent variables, and overall model fit was assessed using multiple indices. Visual path diagrams were generated to illustrate the relationships for each instructional group. All data were screened prior to analysis, and missing data were minimal and handled using pairwise deletion.

3.5. Ethical considerations

Prior to data collection, institutional approval was obtained from Abai Kazakh National Pedagogical University (dated 17 February 2025), and relevant permissions were secured to distribute the survey instruments to students enrolled in visual arts and design programs. Participation in the study was voluntary, and all respondents were informed about the purpose of the research, the confidentiality of their responses, and their right to withdraw at any time without penalty. Informed consent was obtained from each participant prior to completing the questionnaire. No identifying personal information was collected, ensuring complete anonymity and privacy.

4. RESULTS AND DISCUSSION

The results present findings from a multi-group SEM analysis. The analysis proceeded in several steps: evaluation of model fit indices, examination of measurement model reliability and validity, comparison of structural path coefficients across groups, and interpretation of path diagrams. Both the measurement and structural components of the model were assessed for adequacy and invariance to determine whether the conceptual framework held consistently across instructional contexts. The structural model hypothesized the following paths: i) PrblS was regressed on Crtvt and TchAd; ii) Anlyt was regressed on PrblS, Crtvt, and TchAd; and iii) SlfRf was also regressed on PrblS, Crtvt, and TchAd. Table 1 presents the Chi-square test results for the hypothesized user model compared to the baseline model in the context of multi-group SEM.

Table 1. Chi-square test statistics for the user and baseline models in multi-group SEM

Label	χ^2	df	p
User model	993	558	<.001
Baseline model	139524	600	<.001
Scaled user	1197	558	<.001
Scaled baseline	19813	600	<.001

As indicated in Table 1, the user model yielded a chi-square value of $\chi^2(558)=993$, $p<.001$, and a scaled Chi-square value of $\chi^2(558)=1197$, $p<.001$. In contrast, the baseline model, which assumes no relationships among observed variables, produced a much higher Chi-square value ($\chi^2(600)=139,524$), and the scaled baseline model yielded $\chi^2(600)=19,813$, both significant at $p<.001$. Table 2 presents key model fit indices reported across classical, robust, and scaled estimation methods.

As seen in Table 2, the standardized root mean square residual (SRMR) values ranged from .058 to .06, which fall within acceptable limits ($\leq .08$), indicating that the residuals between the observed and predicted covariances are acceptably small [26]. The root mean square error of approximation (RMSEA) values ranged from .079 (classical) to .096 (scaled), with associated 95% confidence intervals (CI). The classical RMSEA of .079, with a CI of [.071, .087], approaches the conventional threshold for good fit ($\leq .08$), whereas the scaled RMSEA of .096, CI [.089, .104], slightly exceeds this boundary.

However, given the complexity of the model and the robustness of the estimation method, these values may still be considered acceptable for an exploratory structural model [27]. All RMSEA p-values were statistically significant ($p<.001$), which is common in large samples. The SRMR and RMSEA values provide evidence of a reasonable to moderately good model fit, supporting the validity of the proposed measurement and structural model for further interpretation. Table 3 displays several incremental fit indices that compare the hypothesized user model to a null baseline model in the multi-group SEM analysis.

Across all indices, Table 3 indicates excellent model fit. The comparative fit index (CFI), Tucker-Lewis index (TLI), non-normed fit index (NNFI), relative noncentrality index (RNI), and incremental fit index (IFI) all achieved values of .997, exceeding the widely accepted threshold of .95 for good fit [26]. Other indices such as the normed fit index (NFI) and relative fit index (RFI) also indicated strong fit, with values of .993 and .992, respectively. The parsimony normed fit index (PNFI), which adjusts for model complexity, was slightly lower at .923, but still well above the minimum acceptable value of .50 [28]. Table 4 presents additional fit indices to further assess the adequacy of the hypothesized SEM.

Table 2. Fit indices for the structural equation model

Type	SRMR	RMSEA	95% CI		RMSEA p
			Lower	Upper	
Classical	.06	.079	.071	.087	<.001
Robust	.058				
Scaled	.058	.096	.089	.104	<.001

Table 3. Incremental fit indices comparing the user model to the baseline model

Indexes	Model
CFI	.997
TLI	.997
Bentler-Bonett NNFI	.997
RNI	.997
Bentler-Bonett NFI	.993
Bollen's RFI	.992
Bollen's IFI	.997
PNFI	.923

As seen in Table 4, the goodness of fit index (GFI) and adjusted goodness of fit index (AGFI) were .992 and .988, respectively, both indicating an excellent model fit, as values above .90 are generally considered acceptable [29]. The parsimony goodness of fit index (PGFI) was .692, indicating a reasonable balance between model fit and complexity. The Hoelter critical N, which estimates the minimum sample size required for the model to be considered a good fit at specified significance levels, was 153.774 ($\alpha=.05$) and 159.889 ($\alpha=.01$). Since these values are above 150, they further support the acceptability of the model given the actual sample size of 249 [30]. Table 5 presents the standardized path coefficients from the multi-group SEM analysis comparing students instructed in Kazakh (1) and Russian (2) groups.

Table 4. Additional fit indices for the structural equation model

Additional fit indices	Model
Hoelter critical N (CN), $\alpha=.05$	153.774
Hoelter critical N (CN), $\alpha=.01$	159.889
GFI	.992
AGFI	.988
PGFI	.692

Table 5. Standardized path coefficients for the structural equation model by language group

Group	Dep	Pred	Estimate	SE	Lower	Upper	β	z	p
1	Anlyt	PrblS	.649	.0749	.5022	.796	.623	8.66	<.001
	Anlyt	Crtvt	.167	.0489	.0713	.263	.173	3.42	<.001
	Anlyt	TchAd	.121	.0765	-.0292	.271	.131	1.58	.114
	PrblS	Crtvt	.19	.0595	.0732	.306	.205	3.19	.001
	PrblS	TchAd	.668	.0537	.5631	.773	.756	12.45	<.001
	SlfRf	Crtvt	.342	.0657	.2127	.47	.327	5.2	<.001
	SlfRf	PrblS	.411	.0739	.2665	.556	.365	5.57	<.001
	SlfRf	TchAd	.296	.0659	.1668	.425	.297	4.49	<.001
2	Anlyt	PrblS	.649	.0749	.5022	.796	.691	8.66	<.001
	Anlyt	Crtvt	.167	.0489	.0713	.263	.173	3.42	<.001
	Anlyt	TchAd	.121	.0765	-.0292	.271	.127	1.58	.114
	PrblS	Crtvt	.19	.0595	.0732	.306	.185	3.19	.001
	PrblS	TchAd	.668	.0537	.5631	.773	.66	12.45	<.001
	SlfRf	Crtvt	.342	.0657	.2127	.47	.321	5.2	<.001
	SlfRf	PrblS	.411	.0739	.2665	.556	.398	5.57	<.001
	SlfRf	TchAd	.296	.0659	.1668	.425	.283	4.49	<.001

Across both groups, the strongest and most significant predictor of Anlyt was PrblS, with a standardized coefficient of $\beta=.623$, $p<.001$, as in Table 5. Crtvt also significantly predicted Anlyt in both groups ($\beta=.173$, $p<.001$), while TchAd was not a significant predictor of Anlyt ($p=.114$). For PrblS, both Crtvt and TchAd were significant and positive predictors across groups (β s ranging from .205 to .756, all $ps<.001$). Regarding SlfRf, all three predictors, Crtvt, PrblS, and TchAd, had significant effects (β s from .297 to .398, $ps<.001$). Table 6 presents internal consistency reliability and convergent validity indices for each latent construct, calculated separately for the Kazakh (1) and Russian (2) instructional groups.

The constructs demonstrated excellent internal consistency in Table 6, with ordinal Cronbach's alpha (α) values ranging from .914 to .956 and McDonald's omega (ω_1 , ω_2 , ω_3) values ranging from .892 to .977, all well above the conventional threshold of .70 [31]. The AVE scores for all constructs were above .68, surpassing the accepted benchmark of .50 [32]. These values confirm that the latent constructs are measured reliably and consistently across both language groups. Figure 1 illustrates the standardized SEM for the Kazakh-instructed student group, showing both the measurement and structural components of the model.

Table 6. Reliability and convergent validity indices by language group

Group	Variable	α	Ordinal α	ω_1	ω_2	ω_3	AVE
1	Anlyt	.947	.947	.927	.927	.93	.785
1	PrblS	.901	.914	.892	.892	.897	.685
1	Crtvt	.944	.956	.94	.94	.944	.816
1	SlfRf	.941	.947	.932	.932	.942	.794
1	TchAd	.939	.952	.943	.943	.977	.834
2	Anlyt	.909	.923	.896	.896	.903	.714
2	PrblS	.928	.934	.914	.914	.939	.767
2	Crtvt	.909	.93	.909	.909	.921	.743
2	SlfRf	.908	.929	.916	.916	.937	.747
2	TchAd	.902	.923	.896	.896	.902	.711

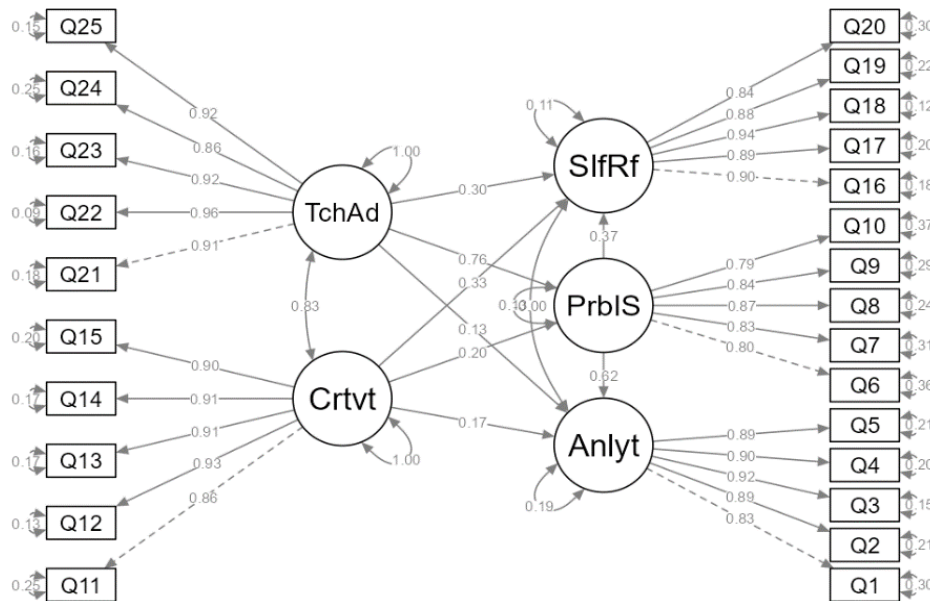


Figure 1. Structural equation model for the Kazakh-instructed group

All latent variables in Figure 1 are indicated by five observed variables, each with strong standardized factor loadings (ranging approximately from .83 to .94), confirming good construct validity. On the structural side, the strongest predictive relationship is observed from PrblS to Anlyt ($\beta=.62$), indicating that students who engage more frequently in PrblS tend to demonstrate stronger Anlyt in the context of digital art. Additionally, Crtvt strongly predicts PrblS ($\beta=.76$) and moderately predicts SlfRf ($\beta=.30$) and Anlyt ($\beta=.17$).

TchAd also significantly influences PrblS ($\beta=.33$) and SlfRf ($\beta=.11$), though its direct effect on Anlyt appears weaker ($\beta=.13$). Collectively, these paths support the model’s hypothesized structure, where Crtvt and TchAd function as exogenous variables shaping PrblS, Anlyt, and SlfRf. Figure 2 displays the structural equation model for students in the Russian-instructed group.

As seen in Figure 2, the measurement model shows strong standardized factor loadings for all observed indicators on their respective latent variables, with values generally above .80, confirming good internal consistency and construct validity. As in the Kazakh-instructed group, PrblS remains the strongest predictor of Anlyt with a path coefficient of $\beta=.69$, slightly higher than the Kazakh group. Crtvt significantly predicts PrblS ($\beta=.68$) and maintains a weaker direct effect on Anlyt ($\beta=.17$) and SlfRf ($\beta=.28$). TchAd plays a more modest role in this group, predicting PrblS ($\beta=.32$) and SlfRf ($\beta=.22$) with moderate coefficients, while its direct influence on Anlyt remains minimal ($\beta=.13$), similar to the Kazakh group. To sum up, the structure of the model in the Russian group aligns closely with the Kazakh group, indicating a consistent cognitive pathway across instructional languages. However, slightly stronger effects of PrblS on analytical outcomes in the Russian group may reflect subtle differences in cognitive strategy or instructional emphasis.

This study examined the structural relationships among Crtvt, TchAd, PrblS, Anlyt, and SlfRf in the context of digital art education. The SEM results revealed that Crtvt and TchAd were significant predictors of students’ problem-solving skills. In turn, PrblS was the strongest predictor of both Anlyt and SlfRf. Crtvt also directly contributed to SlfRf and Anlyt, albeit to a lesser extent. TchAd had a moderate impact on PrblS and SlfRf but was not a strong direct predictor of Anlyt. Importantly, these relationships held consistently across

both Kazakh- and Russian-instructed groups, supporting the structural and measurement invariance of the model. These findings indicate that the cognitive pathways associated with digital art learning are similar across instructional languages.

The findings align with and expand on prior research exploring how digital art supports higher-order thinking skills. Consistent previous studies [8], [22], this study demonstrates that creative engagement using digital tools significantly enhances students' problem-solving abilities. The strong predictive role of Crtvt in this model affirms its central place in critical thinking development, as theorized by Dewey [11], as well as Runco and Acar [33], who emphasized that Crtvt involves active inquiry and reflective decision-making.

TchAd also contributed to cognitive development, supporting earlier claims [20], [21] that digital fluency enhances students' capacity to interact with complex tools, facilitating cognitive flexibility. The current study extends these findings by demonstrating that adaptability supports metacognitive outcomes like SlfRf, in addition to PrbIS. This reflects what Daft and Lengel [25] media richness theory suggests that digital tools provide feedback-rich environments conducive to reflection and judgment.

Most notably, PrbIS emerged as a critical mediating factor between Crtvt, adaptability, and higher-order outcomes such as Anlyt and reflection. This aligns with constructivist theories of learning [34], which view knowledge as actively constructed through exploration and challenge. In digital art, students iteratively address creative and technical problems, which appears to develop the analytical mindset needed for evaluating and refining their work [2]. The visual problem-solving involved in layout, color balancing, and tool usage may mirror the analytical processes used in non-art contexts, supporting the broader educational value of digital media arts. One of the study's most important contributions is the confirmation of cross-group model invariance, indicating that the relationships among Crtvt, adaptability, PrbIS, and critical thinking are robust across linguistic and instructional contexts. Both Kazakh- and Russian-instructed students exhibited nearly identical patterns in factor loadings and path coefficients.

This finding aligns with broader discussions of digital art's transcultural educational relevance [3], [4], supporting the idea that digital media environments improve common modes of engagement and cognition. As Henriksen *et al.* [21] argue, while cultural context shapes expression, digital platforms create convergences in how students explore, revise, and reflect. The lack of significant variation in structural pathways suggests that digital Crtvt, technological fluency, and iterative PrbIS operate as universal mechanisms for cognitive growth in the arts. Moreover, this finding contributes to the limited body of comparative educational research involving bilingual or multilingual instruction settings.

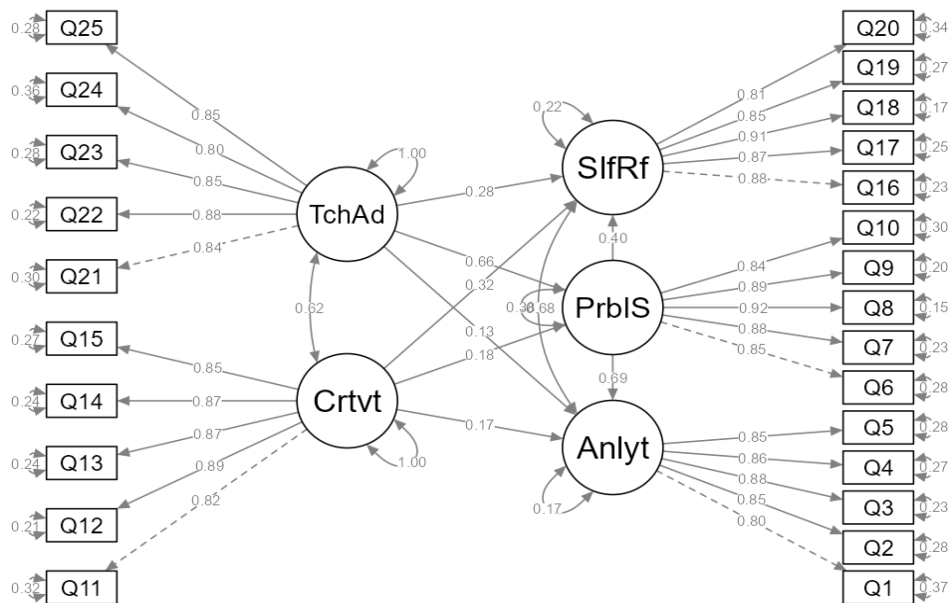


Figure 2. Structural equation model for the Russian-instructed group

5. CONCLUSION

The findings show the pivotal role of integrating digital art into educational curricula to enhance critical thinking skills. By engaging in digital art activities, students develop Crtvt and TchAd, which are foundational for effective PrbIS. Educators should design learning experiences that encourage creative

exploration and the use of digital tools, thereby fostering an environment conducive to higher-order cognitive development. This approach aligns with the growing emphasis on 21st-century skills, preparing students for complex problem-solving in various contexts.

The demonstrated invariance across Kazakh and Russian instructional groups shows that digital art education can exceed linguistic and cultural boundaries. Policymakers should consider incorporating digital art programs universally, leveraging their potential to encourage critical thinking skills irrespective of students' backgrounds. This universality supports the development of standardized curricula that stress digital art, ensuring equitable access to these cognitive benefits.

For the limitations to this study, first, the two instructional language groups (Kazakh and Russian) were not equally represented (63% Kazakh vs. 37% Russian). This could affect the sensitivity of the multi-group analysis and may obscure smaller differences between groups. Second, while the instrument was reviewed and piloted, it was newly developed and used for this study. Although reliability was supported through reliability indices, the lack of extensive validation across different populations may limit confidence in generalizing findings beyond this context. Future research could explore the role of teacher guidance, classroom environment, peer collaboration, or access to technology in shaping students' experiences with digital art and critical thinking.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Gulvira Togabayeva	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Rabilova Zoya		✓				✓		✓	✓	✓	✓	✓		
Miyat Janayev		✓	✓	✓		✓	✓			✓	✓			
Gulnar Shaizadanova		✓	✓		✓			✓		✓			✓	
Anarbek Kozybay	✓	✓			✓		✓		✓	✓		✓		

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : **O**riting - **O**riginal Draft

E : **E**riting - **R**eview & **E**ditng

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

All participants were informed about this study.

ETHICAL APPROVAL

This study was approved by the Ethics Committee of Abai Kazakh National Pedagogical University.

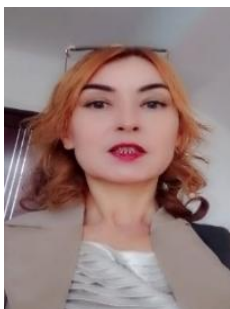
DATA AVAILABILITY




The data is available openly from the correspondent of others.

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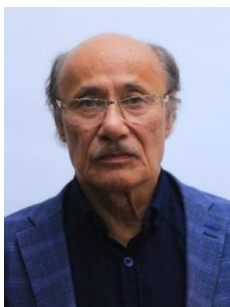
BIOGRAPHIES OF AUTHORS






Gulvira Togabayeva    has been working in the Design Department of Almaty Technological University (ATU) since 2017. She is currently a doctoral candidate at the Abai Kazakh National Pedagogical University (KazNPU). She is fluent in modern, innovative educational technologies and methods, which she effectively applies in practice. She possesses a solid foundation of knowledge and skills that meet the requirements of modern educational standards. Her current research, “Digital Art”, examines the critical thinking of art students. Her research in the field of art is innovative. She can be contacted at email: togabaevagulvira17@gmail.com.






Rabilova Zoya    has been working at Abai Kazakh National Pedagogical University since 1994. Since the 2022/2023 academic year to the present, she has been serving as acting associate professor of the Department of Art Education at Abai KazNPU; Chair of the Academic Council of the Institute of Arts, Culture, and Sports (2019–2023); Head of the republican educational and methodological council of the group for the management of educational and methodological associations-projects for the training of teachers in fine arts and drafting (UMO-GUP/RUMS). She is an author of numerous scientific publications (50 articles, including 11 in journals approved by the higher attestation commission and 2 indexed in Scopus), as well as 7 educational and methodological manuals and educational programs for bachelor’s, master’s, and doctoral levels. She can be contacted at email: zoya.rabilova@mail.ru.






Miyat Janayev    worked as a lecturer at the Zhambyl Pedagogical Institute from 1980 to 1982. From 1982 to 1984, he was a research intern at the Scientific Research Institute of Art Education of the Academy of Pedagogical Sciences of the USSR in Moscow. In 1988, he defended his candidate’s dissertation at the Scientific Research Institute of Art Education of the Academy of Pedagogical Sciences of the USSR in Moscow. Since 1978, he has participated in city, regional, national, and international exhibitions of creative works in painting. From 2003 to 2006, he studied in the doctoral program at Abai Kazakh National Pedagogical University. In 2007, he completed his doctoral dissertation on the topic: “Philosophy of Culture in the System of Art and Pedagogical Education. He can be contacted at email: miyat53@mail.ru.



Gulnar Shaizadanova    is an associate professor, International Educational Corporation (Kazakh Leading Academy of Architecture and Civil Engineering); Member of the Kazakhstan Union of Designers. Her main research results and developments for the years 2020–2025 have been published in scholarly works, including three articles in journals indexed in the Scopus database. In addition, she has more than 20 publications in journals recommended by the committee for quality assurance in the sphere of science and higher education. She can be contacted at email: gulnar_1178@mail.ru.



Anarbek Kozybay    is a doctor of pedagogical sciences, professor at Abai Kazakh National Pedagogical University. He is professor at the Kazakh National Pedagogical University named after Abai, specializes in pedagogical sciences and provides scientific guidance to students at all levels of education. His work focuses on the development of innovative educational methodologies, supervision of research projects for undergraduates and doctoral students, and the advancement of artificial intelligence integration in teaching. He has published extensively in international journals and is the author of numerous textbooks and monographs, making significant contributions to the field of education and pedagogy. He can be contacted at email: k.anarbek@gmail.com.