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THE ASSOCIATIVE ROLES OF HIGHER ORDER THINKING SELF-EFFICACY AND MULTIPLE INTELLIGENCES IN PRESERVICE SCIENCE TEACHERS' 21ST CENTURY LEARNER SKILLS

Fulya Zorlu

Abstract. *As 21st century education increasingly requires preservice teachers to develop advanced cognitive and metacognitive competencies, understanding the patterns of association related to these competencies has become an important concern in teacher education research. A review of the literature revealed an absence of studies examining the associations among multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills. Therefore, this study aimed to examine the structural associations among preservice science teachers' multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills through SEM path analysis. A correlational research design was employed with a sample of 334 preservice science teachers from Türkiye. According to the findings, bodily-kinesthetic, interpersonal, naturalistic, and intrapersonal intelligences were directly associated with at least two dimensions of 21st century learner skills. Additionally, statistically significant indirect associations were observed among selected multiple intelligence domains, higher order thinking self-efficacy, and 21st century learner skills within the hypothesized model. These results should be interpreted as statistical associations within a theoretically specified, cross-sectional model rather than as evidence of causal effects. Education programs may consider integrated instructional approaches that address multiple intelligence domains and higher order thinking self-efficacy in efforts to support preservice teachers' 21st century learner skills.*

Keywords: *21st century learner skills, higher order thinking self-efficacy, multiple intelligences, structural equation modeling*

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Introduction

Humans, compared to other living beings, exhibit a more complex and advanced structure in terms of intelligence due to their highly developed cognitive capacity and thinking abilities. In this context, intelligence is addressed within the literature through various theoretical frameworks, given its complex nature and its determining role in individuals' learning processes, skills, and achievements. According to the classical psychometric approach, intelligence is defined as the ability to respond accurately and effectively to questions on intelligence tests (Deary et al., 2010). Additionally, some perspectives examine intelligence as a multidimensional and complex concept that takes into account individuals' abilities and strengths in various fields (Gardner, 2013). These perspectives address cognitive capacities from a holistic standpoint, considering different environmental, cultural, and experiential contexts. In this regard, the Theory of Multiple Intelligences developed by Howard Gardner, which examined different forms, types, and processes of the mind, offers an inclusive approach by proposing that individuals may possess different types of intelligence (Gardner, 2024).

The theory of multiple intelligences assumes that people have different types of intelligence and classifies them into eight categories: "logical-mathematical", "verbal-linguistic", "musical-rhythmic", "visual-spatial", "bodily-kinesthetic", "interpersonal (social)", "intrapersonal", and "naturalistic" (Gardner, 1999; 2013). Logical-mathematical intelligence is the ability to think effectively using numbers, logic, and abstract concepts. It enables problem solving, reasoning, and analysis. Verbal-linguistic intelligence involves mastering the grammar, meaning, and expressive features of language. This allows for effective communication and learning. Visual-spatial intelligence includes visualizing objects in the mind. It also involves perceiving shape, color, and spatial associations. This intelligence allows for the expression of these perceptions visually. Bodily-kinesthetic intelligence refers to learning, problem

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solving, and expressing oneself through the use of the body and motor skills. Musical-rhythmic intelligence involves expressing, perceiving, and learning emotions through sound, melody, rhythm, and music. Interpersonal (social) intelligence is the ability to communicate effectively with others. It also involves empathizing, understanding human relationships, and developing harmonious interactions. Intrapersonal intelligence involves becoming aware of and understanding one's own emotions, thoughts, and goals. This allows for the management of oneself and the making of personal decisions. Naturalistic intelligence is the ability to observe nature, recognize and classify living things, and understand environmental changes (Gardner, 2013). Relating students' multiple intelligences to classroom topics allows each individual to demonstrate their potential in their unique area of development, thereby enhancing educational quality (İflazoğlu, 2008; Yavich & Rotnitsky, 2020). To improve the quality and individualization of educational practices, Shearer (2018) emphasized the importance of supporting multiple intelligence theory with neuroscientific foundations.

Studies have examined classroom practices (Armstrong, 2018; Tiansoodeenona & Sitthitikul, 2024), assessment processes (Stefanakis, 2002), and teacher education and professional development (Hanafin, 2014) in the theory of multiple intelligences in education. Additionally, existing studies have defined intelligences and examined their associations with various individual and environmental variables. Maspul (2023) emphasized that course content structured with the multiple intelligences approach has the potential to reveal individual abilities. Arns (2021), on the other hand, drew attention to the importance of quality learning environments in developing different intelligences. Hernández et al. (2019) measured Gardner's intelligences separately and demonstrated that each type of intelligence should be evaluated on different dimensions. They also showed that possible variables related to multiple intelligences can be addressed independently. Accordingly, the meta-synthesis study conducted by Aslan-Efe and Bakçı (2022) underscored the significance of evaluating the theory of multiple intelligences from various perspectives.

Today, individuals are expected to possess not only knowledge but also various skills, such as creativity, critical thinking, problem solving, digital literacy, and cooperation (Deniz & Şahin-Kürşad, 2023; McGregor & Kearton, 2010). These skills are referred to as 21st century skills and are defined as the "core competencies necessary to succeed in the modern world" (Partnership for 21st Century Skills [P21], 2019). Martin (2018) defined these skills as the ability to reveal one's potential in areas such as complex problem solving, critical thinking, creativity, cooperation, and digital literacy. In this context, 21st century skills should be addressed through a multidimensional approach that enables individuals to succeed in educational, professional, and social life (Orhan-Göksün, 2016; Sopin & Sanrattana, 2023). Partnership for 21st Century Skills [P21] recommends considering these skills not only as academic knowledge, but also as a holistic structure that encompasses life and career skills, as well as learning and innovation competencies. While there are different classifications, all 21st century skills support one another, and their importance continues to grow (González-Pérez & Ramírez-Montoya, 2022; Seitz & Hill, 2021). It should be noted that this study adopts the more specific construct of "21st century learner skills," as operationalized by Orhan-Göksün (2016), which refers to a pedagogically focused subset of the broader 21st century skills framework. While "21st century skills" encompasses a wide range of competencies applicable across professional and social domains, "21st century learner skills" specifically captures the cognitive, autonomous, cooperative, and innovative capacities most directly relevant to the formal learning context. These two terms are therefore related but not interchangeable, and the present study uses them accordingly throughout.

Considered one of the most controversial topics of the 21st century and frequently discussed in the literature, this scope highlights metacognitive thinking (Cengelci & Egmir 2022), self-regulation (Tanti et al. 2020), information literacy (Tican & Deniz 2019), and professional development (Tawiah 2015) stand out as prominent areas of research. Annetta et al. (2020) modeled individual cognitive differences with high accuracy using artificial neural networks to design science-based educational games grounded in 21st century skills. Studies on these skills demonstrate that they are critical for adapting to a complex, changing, digitalized world. Accordingly, individuals' roles and competencies have been transformed alongside the conditions of the era, enabling societies to adapt more effectively to global realities, boost labor productivity, and develop more comprehensive educational systems in economic and political terms (Bakir, 2019; Zohar & Dori, 2003).

In the transformative process, the Organization for Economic Cooperation and Development (OECD, 2019) emphasized that individuals should not only recall knowledge but also transform and apply it to new situations, demonstrating higher order thinking. As possessing basic skills is no longer sufficient, higher order thinking skills have become a key determinant of educational quality. Schraw and Dennison (1994) argue that individuals' ability to effectively use these skills is closely related to their self-efficacy and perceptions of higher order thinking. Higher order thinking self-efficacy refers to students' perceptions of their cognitive processes and their self-efficacy about how well they can control these processes (Efklides, 2008). Veenman et al. (2006) demonstrated that students with

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positive metacognitive beliefs approach problem solving, decision making, and complex learning tasks more effectively. Moreover, these beliefs encourage students to consciously and systematically use learning strategies, enhancing motivation and positively influencing academic achievement (Tanner, 2012). In educational settings, higher order thinking self-efficacy requires support not only of cognitive skills, but also of metacognitive awareness (Pintrich, 2002). Zohar et al. (2001) stated that teachers hold restrictive beliefs about the applicability of higher order thinking skills among certain groups of students. Therefore, it is essential to provide students with opportunities to recognize, evaluate, and direct their own thinking processes for the sustainable development of higher order thinking skills (Delaney et al., 2022; Murphy & Rodríguez-Manzanares, 2008; Schraw, 1998). However, the relevant literature reveals that studies focusing on higher order thinking self-efficacy are limited, and students' awareness of this self-efficacy is often insufficient, regardless of level. Ragab et al. (2024) emphasized the importance of prioritizing higher order thinking in teacher education and called for more research on the topic.

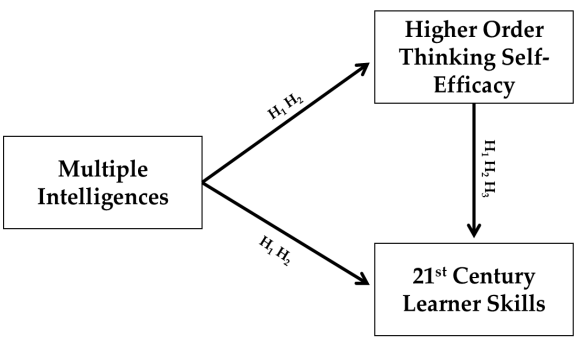
Research Aim and Research Questions

According to Sternberg (2021), intelligence has gained a central role in contemporary education as a multidimensional construct encompassing individuals' capacity to access, transform, and solve complex problems. In this context, what matters is not only what individuals know, but also how they transform their knowledge, apply it across different contexts, and regulate their cognitive processes. As 21st century education requires the development of complex cognitive, metacognitive, and adaptive skills, understanding the patterns of association related to these skills has become a critical concern in teacher education research.

Although there are studies examining the associations among higher order thinking self-efficacy, multiple intelligences, and 21st century learner skills, these constructs have predominantly been addressed through bivariate associations. This situation highlights a significant need to examine, within a holistic framework, the interactional structure among individuals' cognitive potentials, their beliefs about using these potentials, and the resulting competencies (Bandura, 1997; OECD, 2019; P21, 2019). The present study not only examines whether higher order thinking self-efficacy, multiple intelligences, and 21st century learner skills are related, but also tests a theoretically specified model of their structural associations (Figure 1).

The proposed model is grounded in Bandura's (1997) Social Cognitive Theory and Pintrich's (2002) metacognitive framework. From this perspective, individuals' cognitive capacities may be more meaningfully related to 21st century learner skills when considered together with beliefs about their own thinking processes. Accordingly, it is expected that different intelligence profiles may be associated with individuals' confidence in their higher order thinking abilities, which may also be related to 21st century learner skills. Within this framework, higher order thinking self-efficacy is positioned as an intervening construct in the indirect associations between multiple intelligences and 21st century learner skills. Therefore, the model was constructed to examine the direct associations of multiple intelligences on 21st century learner skills, the indirect associations through higher order thinking self-efficacy, and the direct associations of higher order thinking self-efficacy on 21st century learner skills (Figure 1).

Figure 1
The Hypothesized Model



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Accordingly, this study aimed to examine the structural associations among preservice science teachers' multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills, including cognitive, autonomous, cooperation and flexibility, and innovation skills. The direct and indirect associations among these variables were tested using structural equation modeling (SEM). The research hypotheses and the model in Figure 1 were tested.

A study of preservice science teachers reported significant and positive associations between multiple intelligences and 21st century learner skills. The study also found that multiple intelligences were significantly associated with 21st century learner skills (İpekşen & Zorlu, 2022). Similarly, studies have demonstrated that multiple intelligences were associated with problem solving skills (Genç, 2012), creativity (Yang & Fan, 2022), and higher order thinking (Dawahdeh & Mai, 2021). Based on these associations, multiple intelligence profiles may be related to individuals' cognitive and metacognitive processes and may be relevant to 21st century learner skills. Therefore, it is expected that preservice science teachers' multiple intelligences and higher order self-efficacy beliefs related to higher-order thinking will be associated with 21st century learner skills. In this context, hypothesis H_1 was developed.

H_1: Preservice science teachers' 21st century learner skills, multiple intelligences, and higher order thinking self-efficacy are associated with one another.

The literature emphasizes that multiple intelligences are associated not only with learning processes, but also with various cognitive and higher order thinking skills. Sholiah et al.'s (2020) study revealed a strong and significant association between multiple intelligences and higher order thinking skills. Similarly, Dawahdeh and Mai (2021) demonstrated that multiple intelligences were significantly associated with higher order cognitive performance and thinking skills. In this context, it is expected that the preservice science teachers' multiple intelligences and their self-efficacy beliefs related to higher order thinking will exhibit significant associations with 21st century learner skills. In this context, hypothesis H_2 was developed.

H_2: Preservice science teachers' 21st century learner skills are associated with their multiple intelligences and their higher order thinking self-efficacy.

Schraw et al. (2006) demonstrated that higher order thinking and metacognitive skills are more strongly associated with learning outcomes when students have strong beliefs in their self-efficacy and self-regulation. Additionally, evidence suggests that the association between cognitive competencies and academic performance and learner skills is linked indirectly through motivational beliefs rather than directly (Pintrich, 2004). Accordingly, it is hypothesized that higher order thinking self-efficacy may be involved in the indirect associations between preservice science teachers' multiple intelligences and their 21st century learner skills. In this context, hypothesis H_3 was developed.

H_3: Higher order thinking self-efficacy is involved in indirect associations between preservice science teachers' multiple intelligences and 21st century learner skills.

Research Methodology

Design

This study adopted a quantitative research approach and employed a correlational research design to examine the associations among variables. Path analysis within structural equation modeling (SEM) was conducted to test the hypothesized model and the direct and indirect associations among multiple intelligences, higher order thinking self-efficacy, and preservice science teachers' 21st century learner skills. The analysis followed a two-step procedure: first, confirmatory factor analysis (CFA) was performed to evaluate the measurement model in terms of validity and reliability; second, the path analysis within structural equation modeling (SEM) was tested to examine the direct and indirect paths in the model (Figure 1).

Given the aim of the study, examined variables, and sample characteristics, the "Multiple Intelligence Inventory (MII)", "Higher Order Thinking Self-Efficacy Scale (HOTSE)", and "21st Century Learner Skills Scale (21stCLSS)" were employed to collect data. The Multiple Intelligences Inventory (MII) was adapted into Turkish by Y. Özden. The MII consists of eight intelligences: "Verbal-Linguistic (VL)", "Logical-Mathematical (LM)", "Visual-Spatial (VS)", "Musical-Rhythmic (MR)", "Bodily-Kinesthetic (BD)", "Interpersonal (Social) (ILS)", "Intrapersonal (IL)" and "Naturalistic (NC)." The inventory includes 10 items for each intelligence domain. Each domain can receive a score ranging from 10 to 50 (Özden, 2014). Expert reviews and a pilot implementation process were conducted to establish the validity of the MII. The factor structure was validated using factor analysis on the obtained data. HOTSE is a subscale of the "Science Learning Self-Efficacy Questionnaire (SLSQ)". The SLSQ was initially developed by Lin and Tsai (2013) and

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adapted to Turkish by Zorlu (2017). HOTSE consists of six items. Expert reviews and a pilot implementation process were conducted to establish the validity of the HOTSE. 21stCLSS was developed by Orhan-Göksün (2016). In the present study, the outcome variable was not the broader construct of 21st century skills, but the specific construct of 21st century learner skills as operationalized by Orhan-Göksün (2016). The scale consists of four factors: "Cognitive Skills (CS)", "Autonomous Skills (AS)", "Cooperation and Flexibility Skills (CFS)" and "Innovation Skills (IS)", with 31 items in total. In this context, 21st century learner skills in this study were included as cognitive, autonomous, innovation, cooperation and flexibility competencies that focus on the individual's learning process, distinguishing them from the broader construct of 21st century skills. The MII, HOTSE, and 21stCLSS scales were 5-point Likert-type scales. Focus group interviews were conducted for the 21stCLSS, based on literature, expert reviews and a pilot implementation process, to ensure validity. The factor structure was validated using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) on the obtained data. The reliability of the scales was established using the test–retest method.

Sample

The sample of the study consisted of senior preservice science teachers enrolled in science education programs at the faculties of education of three state universities in Türkiye (Kütahya Dumlupınar University, Zonguldak Bülent Ecevit University, and Dokuz Eylül University). The sample was selected using a convenience sampling method. The sample consisted of 334 senior preservice science teachers enrolled at three state universities in Türkiye (Kütahya Dumlupınar University, Zonguldak Bülent Ecevit University, and Dokuz Eylül University) who voluntarily agreed to participate in the study. The study identified 13 observed variables and 21 associations. According to Kline (2023) and Schreiber et al. (2006), at least ten samples are required for each association. Thus, the sample should include at least 210 participants to account for the 21 associations. Since the sample in this study consists of 334 preservice science teachers, the dataset satisfies the criteria for applying structural equation modeling (SEM). Of the preservice science teachers, 106 were male (52 preservice science teachers from Kütahya Dumlupınar University, 30 from Zonguldak Bülent Ecevit University, and 24 from Dokuz Eylül University), and 228 were female (104 from Kütahya Dumlupınar University, 69 from Zonguldak Bülent Ecevit University, and 53 from Dokuz Eylül University). The preservice science teachers in the study were voluntary, and all participants provided informed consent prior to data collection. The inclusion of preservice science teachers from three state universities provided institutional diversity; the sample should not be considered statistically representative of all preservice science teachers in Türkiye.

Procedures

Preservice science teachers were informed about the content and aim of the research. They were introduced to the scales determined within the scope of the study: the "Multiple Intelligences Inventory (MII)", "the Higher Order Thinking Self-Efficacy Scale (HOTSE)", and the "21st Century Learner Skills Scale (21stCLSS)". Then, the MII, HOTSE, and 21stCLSS were administered in that order. Participants were given adequate time to complete each scale.

Data Analysis

The reliability coefficients of the measurement instruments used in this study are presented in Table 1.

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Table 1
Reliability Coefficients of the Measurement Instruments

Instrument	Subscales	Cronbach's α
Multiple Intelligences Inventory (MII)	Verbal-Linguistic (VL)	.87
	Logical-Mathematical (LM)	.80
	Visual-Spatial (VS)	.68
	Musical-Rhythmic (MR)	.86
	Bodily-Kinesthetic (BD)	.72
	Interpersonal (ILS)	.76
	Intrapersonal (IL)	.92
	Naturalistic (NC)	.83
	Total	.86
Higher Order Thinking Self-Efficacy (HOTSE)	HOTSE	.73
21st Century Learner Skills Scale (21stCLSS)	Cognitive Skills (CS)	.89
	Autonomous Skills (AS)	.69
	Cooperation and Flexibility Skills (CFS)	.88
	Innovation Skills (IS)	.76
	Total	.91

In this study, the reliability coefficient of the MII applied to the sample was calculated as .86. The reliability coefficients of the factors (Cronbach's alpha) were calculated to be .87 for VL, .80 for LM, .68 for VS, .86 for MR, .72 for BD, .76 for ILS, .92 for IL, and .83 for NC. The reliability coefficient (Cronbach's alpha) of HOTSE was calculated to be .73. The reliability coefficient of the scale was calculated to be .91. The reliability coefficients of the factors (Cronbach's alpha) were calculated to be .89 for CS, .69 for AS, .88 for CFS, and .76 for IS. As presented in Table 1, the reliability coefficients of the scales, both reported in their original development studies and calculated within the scope of this study, range between .68 and .92. Since all coefficients exceed .60 (Creswell, & Creswell 2022), the scales are considered reliable.

Confirmatory factor analysis (CFA) was conducted to verify the factor structures of the scales and to examine their construct validity (Table 2).

Table 2
CFA Results of the Scales

Scale	Fit Index	Value
MII	χ^2/df (3052)	2.89
	RMSEA	.077
	NFI	.92
	NNFI	.95
	CFI	.95
	GFI	.91
	AGFI	.86

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Scale	Fit Index	Value
HOTSE	χ^2/df (8)	2.21
	RMSEA	.062
	NFI	.96
	NNFI	.96
	CFI	.98
	GFI	.98
	AGFI	.95
21stCLSS	χ^2/df (398)	2.53
	RMSEA	.069
	NFI	.94
	NNFI	.97
	CFI	.96
	GFI	.99
	AGFI	.93

The fit indices of the scales to the results of the CFA meet the commonly accepted criteria in the literature ($0 < \chi^2/df \leq 3$, $0 <$ RMSEA $\leq .08$, $.90 \leq$ NFI, NNFI, CFI, and GFI ≤ 1, and $.85 \leq$ AGFI ≤ 1) (Byrne, 2016; Çelik & Yılmaz, 2016; Kline, 2023) (Table 2). Accordingly, the factor structures of the scales were confirmed, and their validity was established. The normality of the data distribution was examined (see Table 3).

Table 3
Descriptive and Normality Values

Scale	Variables	*M*	Skewness	Skewness Std. Error	Kurtosis	Kurtosis Std. Error	*p*
HOTSE	HOTSE	22.9	-.136	.137	.421	.273	.061
MII	VL	37.29	-.18	.137	.019	.273	.110
	LM	37.93	-.373	.137	-.235	.273	.074
	VS	35.81	.043	.137	.085	.273	.132
	MR	35.52	-.212	.137	.081	.273	.105
	BD	38.74	-.214	.137	-.286	.273	.095
	ILS	36.37	-.109	.137	-.138	.273	.163
	IL	38.29	-.394	.137	.188	.273	.053
	NC	34.92	-.044	.137	-.251	.273	.068
21stCLSS	CS	69.71	-.21	.137	-.268	.273	.056
	AS	20.83	.172	.137	-.295	.273	.054
	CFS	20.22	.303	.137	-.34	.273	.078
	IS	7.63	-.563	.137	.053	.273	.052

Examining Table 3 reveals that the skewness and kurtosis values of the obtained data fall within the range of −1 to +1. Additionally, the ratios of "skewness value/skewness standard error" and "kurtosis value/kurtosis standard error" fall between −1.96 and +1.96. According to Morgan et al. (2004) and Can (2014), these values and ratios indicate that the data are normally distributed. Additionally, the Shapiro–Wilk normality test showed that the data followed a normal distribution ($p > .05$). Because the sample size was sufficient and the data were normally

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distributed, path analysis, a structural equation modeling technique, was conducted to determine the associations between preservice science teachers' multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills. Structural equation modeling (SEM) is a multivariate statistical method that explicitly considers measurement errors of the variables included in a given model, thereby enabling the development, estimation, and testing of complex multivariate models. Path analysis, one of the SEM techniques, allows for the examination of direct and indirect associations among observed variables based on a theoretically grounded model (Byrne, 2016; Kline, 2023). The path analysis was performed using the LISREL program. The Structural Equation Model (SEM) fit evaluation criteria suggested by Çelik and Yılmaz (2016) were used to assess model fit indices (χ^2/df, RMSEA, SRMR, NFI, NNFI, CFI, GFI, and AGFI). Given the cross-sectional and correlational nature of the data, SEM path analysis was used to test theoretically specified patterns of association among the observed variables rather than to establish prediction, causal direction, or causal effects.

Research Results

The findings within the proposed model are presented specifically in association with 21st century learner skills, not the broader construct of 21st century skills. In this study, 21st century learner skills refer to the four learning-oriented skills measured by the "21st CLSS": "Cognitive", "Autonomous", "Cooperation and Flexibility", and "Innovation". Accordingly, all direct, indirect, and total associations reported in this section should be interpreted within the context of preservice teachers' learning-related competencies. The findings were based on data obtained from the direct and indirect associations of pre-service science teachers' higher-order thinking self-efficacy and multiple intelligences on 21st century learner skills. A Pearson correlation analysis was conducted to examine the associations among the variables, and the findings are presented in Table 4.

Table 4
Results of the Pearson Correlation Analysis

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. VL	1.00												
2. LM	.612**	1.00											
3. VS	.567**	.561**	1.00										
4. MR	.512**	.572**	.575**	1.00									
5. BD	.520**	.539**	.472**	.518**	1.00								
6. ILS	.535**	.542**	.560**	.511**	.552**	1.00							
7. IL	.611**	.604**	.557**	.528**	.687**	.601**	1.00						
8. NC	.531**	.546**	.585**	.580**	.549**	.563**	.584**	1.00					
9.HOTSE	.387**	.327**	.348**	.295**	.341**	.338**	.339**	.349**	1.00				
10. CS	.510**	.462**	.437**	.346**	.504**	.439**	.533**	.412**	.546**	1.00			
11. AS	.431**	.366**	.293**	.337**	.352**	.393**	.371**	.373**	.363**	.477**	1.00		
12. CFS	.451**	.403**	.403**	.331**	.384**	.369**	.424**	.398**	.455**	.545**	.451**	1.00	
13. IS	.311**	.326**	.329**	.255**	.322**	.296**	.311**	.296**	.354**	.506**	.324**	.369**	1.00

** p < .01; * p < .05

Examining Table 4 reveals that all the study's variables are positively and statistically significantly correlated ($p < .01$). A path analysis was conducted to verify the structural equation model (SEM) developed to examine the associations among preservice science teachers' multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills. The fit indices obtained from the SEM in our study are presented in Table 5.

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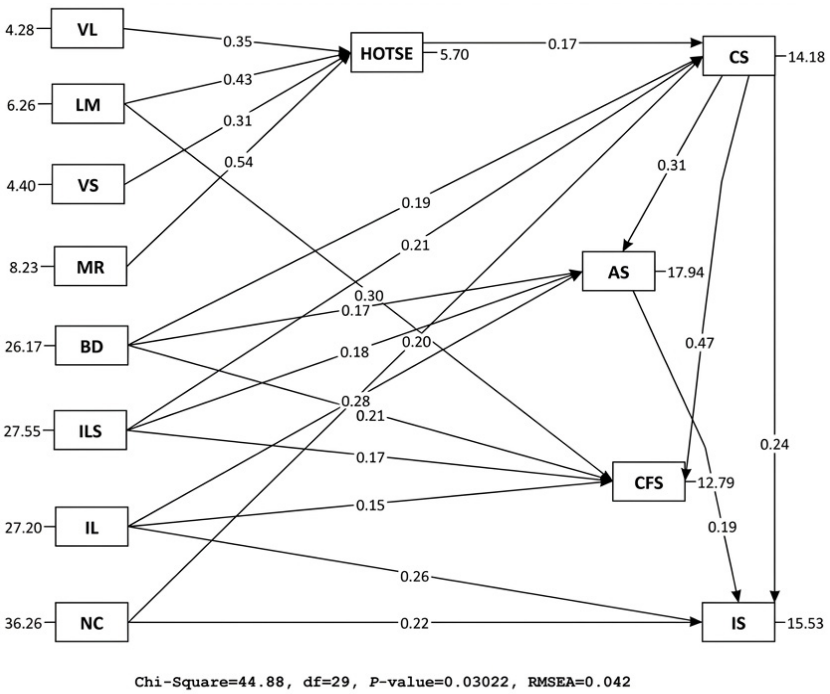
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Table 5
The Fit Indices Obtained from the SEM

Fit Index	Value	Fit
$\chi^2/df(29)$	1.55	Good Fit
p	.030	Good Fit
RMSEA	.042	Good Fit
SRMR	.030	Good Fit
NFI	.99	Good Fit
NNFI	.99	Good Fit
CFI	.99	Good Fit
GFI	.98	Good Fit
AGFI	.93	Good Fit

Examining Table 5 shows that the fit indices of the structural equation model developed in this study are within the 'good fit' range, according to the Structural Equation Model (SEM) fit evaluation criteria suggested by Çelik and Yılmaz (2016): $\chi^2/df = 1.55$, RMSEA = .042, SRMR = .030, NFI = .99, NNFI = .99, CFI = .99, GFI = .98 and AGFI = .93. Figure 2 presents the path diagram of the SEM developed to examine the associations among preservice science teachers' multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills.

Figure 2
Structural Equation Model of the Study



Examining the path diagram of the structural equation model shown in Figure 2 reveals that certain multiple intelligences were directly associated with 21st century learner skills, others were associated with them indirectly through higher order thinking self-efficacy (HOTSE). The direct, indirect, and total association values obtained from the SEM path analysis are presented in Table 6.

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Table 6
Associations of Path Analysis

Dependent Variable	Independent Variable	Direct (β)	Indirect (β)	Total (β)	R^2
HOTSE	VL	.350		.350	.66
	LM	.430		.430	
	VS	.310		.310	
	MR	.540		.540	
	BD			.000	
	ILS			.000	
	NC			.000	
CS	VL		.059	.059	.40
	LM		.072	.072	
	VS		.052	.052	
	MR		.090	.090	
	BD	.190		.190	
	ILS	.210		.210	
	NC	.200		.200	
	HOTSE	.170		.170	
AS	VL		.018	.018	.45
	LM		.022	.022	
	VS		.016	.016	
	MR		.028	.028	
	BD	.170	.060	.230	
	ILS	.180	.060	.240	
	IL	.280		.280	
	NC		.062	.062	
	CS	.310		.310	
CFS	VL		.028	.028	.61
	LM	.300	.030	.330	
	VS		.025	.025	
	MR		.043	.043	
	BD	.210	.090	.300	
	ILS	.170	.100	.270	
	IL	.150		.150	
	NC		.095	.095	
	CS	.470		.470	
IS	VL		.017	.017	.49
	LM		.021	.021	
	VS		.015	.015	
	MR		.026	.026	
	BD		.089	.089	
	ILS		.094	.094	
	IL	.260	.060	.320	
	NC	.220	.050	.270	
	CS	.240		.240	
	AS	.190		.190	

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The direct associations of HOTSE ("Higher Order Thinking Self-Efficacy") were found to be statistically significant for the following variables: MR (β = .54), LM (β = .43), VL (β = .35), and VS (β = .31). The tested model accounted for 66% of the variance in HOTSE (Table 6).

Of the 21st century learner skills, the direct associations of CS ("Cognitive Skills") were found to be statistically significant for the following variables: ILS (β = .21), NC (β = .20), HOTSE (β = .17), and BD (β = .19). Indirect associations through HOTSE were found for MR (β = .090), LM (β = .072), VL (β = .059), and VS (β = .052). The tested model accounted for 40% of the variance in CS. The direct associations of AS ("Autonomous Skills") were found to be statistically significant for the following variables: CS (β = .31), IL (β = .28), ILS (β = .18), and BD (β = .17). Indirect associations through HOTSE and CS were found for NC (β = .062), BD (β = .060), ILS (β = .060), MR (β = .028), LM (β = .022), VL (β = .018), and VS (β = .016). The tested model accounted for 45% of the variance in AS. The direct associations of CFS ("Cooperation and Flexibility Skills") were found to be statistically significant for the following variables: CS (β = .47), LM (β = .30), BD (β = .21), ILS (β = .17), and IL (β = .15). Indirect associations through HOTSE and CS were found for ILS (β = .100), NC (β = .095), BD (β = .090), MR (β = .043), LM (β = .030), VL (β = .028), and VS (β = .025). The tested model accounted for 61% of the variance in CFS. The direct associations of IS ("Innovation Skills") were found to be statistically significant for the following variables: IL (β = .26), CS (β = .24), NC (β = .22), and AS (β = .19). Indirect associations were found through HOTSE, CS, and AS for ILS (β = .094), BD (β = .089), IL (β = .060), NC (β = .050), MR (β = .026), LM (β = .021), VL (β = .017), and VS (β = .015). The tested model accounted for 49% of the variance in IS (Table 6).

Discussion

This study examined the role of higher order thinking self-efficacy and multiple intelligences in preservice science teachers' 21st century learner skills. In line with this examination, the findings obtained from the research were presented and discussed within the framework of the relevant literature. The findings obtained from the SEM path analysis of 21st century learner skills should not be reduced to general 21st century skills. In the present study, the 21st century learner skills were examined as a specific learning-oriented construct operationalized through "Cognitive", "Autonomous", "Cooperation and Flexibility", and "Innovation" skills. Therefore, the results should be interpreted within the context of formal learning and science teacher education rather than as evidence about broader professional, social, or life skills. This distinction is important because the construct measured in this study focuses specifically on how preservice science teachers approach learning processes, regulate their own learning, collaborate with others, adapt to learning situations, and generate innovative learning-related ideas.

According to the findings obtained from the SEM path analysis, higher order thinking self-efficacy was found to be directly associated with "Musical-Rhythmic", "Logical-Mathematical", "Verbal-Linguistic", and "Visual-Spatial" intelligences. Based on these findings, it was concluded that the higher order thinking self-efficacy was associated with the cognitive processes represented by multiple intelligences. In this context, the four intelligences are associated with cognitive processes such as perception, emotional expression, abstract reasoning, and mental visualization (Armstrong, 2018; Gardner, 2013, 2024), which correspond to higher order thinking self-efficacy features including working memory, attention control, cognitive flexibility, and analytical reasoning (Bialystok & DePape, 2009; Moreno et al., 2011; Lai, 2011; Sternberg, 2020; Veenman et al., 2006). These cognitive processes may be relevant to how preservice teachers perceive and regulate their higher order thinking. In the tested model, self-efficacy in higher order thinking appeared to be associated with intelligences involving abstract reasoning, symbolic representation, and mental visualization. Therefore, learning environments that incorporate the cognitive characteristics of these intelligences may be considered in teacher education. Such environments should be interpreted as pedagogical possibilities rather than as evidence of causal effects derived from the present SEM model.

Another important finding was that "Bodily-Kinesthetic," "Interpersonal (Social)," "Naturalistic," and "Intrapersonal" intelligences were directly associated with at least two dimensions of 21st century learner skills. These results are consistent with studies demonstrating associations between multiple intelligences and 21st century learner skills (Supaat et al., 2025). Based on these findings, learning environments designed with these four multiple intelligences in mind may contribute to the development of 21st century learner skills. The prominence of "Bodily-Kinesthetic" intelligence in the model, physically interactive learning environments may play an important role in supporting 21st century learner skills (Armstrong, 2018; Gardner, 2013, 2024; Michelaki & Bournelli, 2016). The association involving "Naturalistic" intelligence, environmental observation, and classification tasks may be meaningfully connected with cognitive and innovation-oriented learning activities in science teacher education. The association involving "Intrapersonal" intelligence points to the relevance of reflective and self-regulatory learning tasks in science teacher education (Gardner, 2013, 2024; Martin,

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2018; Orhan-Göksün, 2016; P21, 2019; Sternberg, 2020; Xu et al., 2023).These associations also point to the relevance of practice-based, activity-oriented, and collaborative learning environments. In this regard, laboratory applications, simulation-based activities, technology-integrated tasks, collaborative learning activities, and real-life problem-solving tasks may provide contexts in which preservice science teachers engage cognitive, autonomous, collaborative, and higher order thinking processes together (Armstrong, 2018; Gardner, 2013, 2024; Husain, 2023; Michelaki & Bournelli, 2016; Zainil et al., 2023; Zorlu & Zorlu, 2021).

Another important finding was that "Cognitive Skills" and "Autonomous" skills were found to be directly associated with "Higher Order Thinking Self-Efficacy.""Innovation" skills were directly associated with "Cognitive" and "Autonomous," whereas "Cooperation and Flexibility" skills were directly associated with "Cognitive" skills. Within the tested model, "Cognitive" skills appeared to occupy a central position in their associations with "Autonomous", "Cooperation and Flexibility", and "Innovation" skills. This pattern is consistent with frameworks that view "cognitive", "autonomous", "collaborative and flexible", and "innovative" learner skills as interrelated dimensions rather than isolated competencies (Fadel & Trilling, 2012; Orhan-Göksün, 2016; Partnership for 21st Century Skills [P21], 2019; Voogt & Roblin, 2012). Moreover, the association of cognition with social interaction, experiential engagement, and environmental awareness is consistent with approaches that emphasize learning as a multidimensional and context-sensitive process (Organisation for Economic Co-operation and Development [OECD], 2019). Similarly, within the P21 framework, the treatment of critical thinking, communication, collaboration, and creativity as interrelated rather than independent skills supports the structural associations obtained in the present study (P21, 2019). Instructional designs in science teacher education may benefit from addressing cognitive, metacognitive, embodied, social, environmental, and innovation-oriented learning dimensions together. Therefore, in instructional efforts aimed at supporting preservice science teachers' 21st century learner skills, cognitive, autonomous, cooperation-flexibility, and innovation-oriented dimensions may be addressed in an integrated manner.

Another important finding was that the preservice science teachers'"Higher Order Thinking Self-Efficacy" mediated the association between "Multiple Intelligences" and other 21st century learner skills ("Autonomous," "Cooperation-Flexibility," and "Innovation"). The higher order thinking self-efficacy appeared to be an important construct in the tested model because it was indirectly associated with 21st century learner skills through selected multiple intelligences. In science education, educational approaches may address multiple intelligences and higher order thinking self-efficacy together as constructs associated with preservice science teachers' 21st century learner skills. The preservice science teachers'"Cognitive Skills" mediated the association between "Higher Order Thinking Self-Efficacy" and other 21st century learner skills ("Autonomous,""Cooperation-Flexibility," and "Innovation"). Based on these findings, it was concluded that cognitive skills depend on core cognitive processes such as understanding, transforming, and transferring information, which support executive functions including self-regulation, decision-making, and problem solving (Fadel & Trilling, 2012; OECD, 2019; Orhan-Göksün, 2016; Sternberg, 2020; Lai, 2011). In line with the Partnership for 21st Century Skills [P21] 2019 framework, cognitive skills function as a foundation for autonomy, collaboration, and innovation. In addition, "Autonomous Skills" mediated the association between cognitive skills and innovation skills. While cognitive skills provide the capacity to process knowledge, autonomous skills enable their effective use through self-regulation (Shi & Yang, 2025). To this association, innovation skills may be linked to the interaction between cognitive processing and self-regulatory capacities. According to the results, the associations in the tested model suggest an interdependent statistical structure among the 21st century learner skills. In this structure, "Cognitive" skills appeared to occupy a central position, whereas "Innovation" skills appeared to be linked to both "Cognitive" and "Autonomous" skills within the tested model. Therefore, when developing preservice science teachers' 21st century learner skills, the initial stage should focus on acquiring and strengthening cognitive processes. Once these cognitive processes are established, the next stage should emphasize developing "Autonomous" and "Cooperative and Flexible" skills. Finally, instructional practices should aim to develop "Innovation" skills.

Conclusions and Implications

This study contributes to the literature by proposing a theoretically grounded structural model that simultaneously integrates preservice science teachers' multiple intelligences and higher order thinking self-efficacy in examining their associations with 21st century learner skills within a single analytical framework. Moving beyond fragmented and bivariate approaches, the model provides a more comprehensive account of how cognitive capacities and metacognitive beliefs are jointly associated with learning-oriented competencies in science teacher education contexts. According to the findings obtained from the study, it was concluded that preservice science teachers' 21st century learner skills, selected multiple intelligences, and higher order thinking self-efficacy are statistically associated constructs within the tested model. Therefore, in the context of science education, curricula may include learning experiences that address

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multiple intelligences and higher order thinking self-efficacy as potentially relevant factors associated with preservice teachers' 21st century learner skills. Although SEM path analysis allowed the testing of theoretically specified direct and indirect associations among the variables, the findings do not establish causal directionality. Therefore, terms such as "direct association," "indirect association," and "explained variance" should be interpreted as statistical associations within the proposed model rather than evidence of causal effects. Because all data were collected at a single time point through self-report scales, the results may also be influenced by common method bias and participants' self-perceptions. Longitudinal or experimental designs are needed in future research to move toward stronger causal inference. Since this study used multiple intelligences and higher order thinking self-efficacy variables, future research could include additional variables to identify other significant associations with preservice science teachers' 21st century learner skills. Future research could build on this work by including preservice teachers from different subject departments in order to conduct comparative analyses. Such comparisons would contribute to the existing literature by highlighting potential differences between disciplines in terms of multiple intelligences, higher order thinking self-efficacy, and 21st century learner skills. In the study, quantitative data were collected using scales. To examine the reasons underlying the associations among the variables from the perspectives of the research participants in greater depth, it is recommended that both qualitative and quantitative data be collected and mixed research methods be employed. Longitudinal studies are recommended to monitor preservice science teachers' "multiple intelligences", "higher order thinking self-efficacy," and "21st century learner skills" scores over time to observe how these associations evolve.

Declaration of Interests

No potential conflict of interest was reported by the author.

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