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Deciphering Kyrgyz science and mathematics teachers' STEM teaching readiness

Ian Phil Canlas [1,2*]

[1] School of Arts and Sciences, University of Central Asia, Naryn, KYRGYZSTAN
[2] School of Graduate Studies, Biliran Province State University, Naval, Biliran Province, PHILIPPINES

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Abstract
This study explored the interdependence of knowledge-base in teaching, STEM career awareness, teaching efficacy, attitudes, and STEM teaching readiness. Using a Likert-scale instrument adapted from literature, 367 public high school science and mathematics teachers from Osh and Naryn regions participated in the study. Partial least squares-structural equation modeling using SmartPLS revealed that STEM teaching readiness could be predicted by knowledge-base in teaching and STEM career awareness, and teaching efficacy and attitudes can be predicted by knowledge base in teaching. Teaching efficacy and attitudes did not have a significant direct effect on STEM teaching readiness, nor a mediating effect between knowledge-base in teaching and STEM teaching readiness and between STEM career awareness and STEM teaching readiness. The hypothesized model may inform relevant policy-making bodies and can be used in developing and implementing a locally-relevant and context-specific STEM professional development for science and mathematics teachers.

Keywords: STEM, Kyrgyzstan, STEM teaching readiness, knowledge-base in teaching, teaching efficacy

INTRODUCTION

Many countries, including the Kyrgyz Republic, are pushing to streamline STEM (*i.e., science, technology, engineering, and mathematics*) education in the school curricula. This may be driven by the numerous environmental and social problems that are new and more complex brought by the advances of the 21st century (Kelley & Knowles, 2016) vis-à-vis the increasing consensus about the essential role of STEM education in economic development, overall national progress, and global competitiveness. As independent disciplines, research on teaching and learning science, technology, engineering, and mathematics, as well as issues and concerns related thereto, are not new. However, the arrival of STEM education philosophy into the science and mathematics school curricula, for example, has increased the bar for the required epistemic fluency levels of science and mathematics teachers-that is, a high level of expertise around science, technology, engineering, and mathematics, and different sets of pedagogical content knowledge (Leonard, 2022). Thus, enhancing science and mathematics teachers' knowledge-base in teaching and other variables associated with STEM teaching is imperative.

Thibaut et al. (2019) defined STEM education as an instructional approach emphasizing deeper connections between STEM disciplines that can be achieved through provisions of design challenges anchored on real-world problems. Nadelson and Seifert (2017) described STEM as the amalgamation of content and concepts from multiple STEM disciplines in a continuum:

(a) segregated (*shorthand for STEM domains, foundational, knowledge level, direct instruction, content level, top-down, highly structured, lower order thinking, and literacy*),

(b) mid-spectrum (*mixed STEM, applications, problem level, guided or modeled, mixed of top-down and bottom-up, some structure, mixture of order thinking, and competency*), and

(c) integrated (*integrated STEM, synthesis, project level, discovery-based, bottom-up, open-ended, ill-structured, and higher order thinking, proficiency*).

✉ ian.canlas@ucentralasia.org **(*Correspondence)**

Contribution to the literature

- This study contributes to the ongoing discourse on STEM education such that it may directly and/or indirectly provide some answers and clarity to the gaps and challenges in the related literature.
- It contributes to the body of knowledge on STEM teaching readiness by providing empirical evidence on the interaction of the variables under study.
- The hypothesized model assessed in this study can inform policymakers and relevant entities responsible for STEM education implementation in the country and similar contexts.

Sanders (2009) pointed out the key elements that resonate with STEM education, including

(a) learning is constructive,
(b) motivation and beliefs are integral to cognition,
(c) social interaction is fundamental to cognitive development, and
(d) knowledge, strategies, and expertise are contextual.

Through the years, a number of hybridized forms of STEM education arose from literature such as STEAM (*i.e., science, technology, engineering, arts, and mathematics*) (Herro & Quigley, 2017), STREAM (*i.e., science, technology, reading, engineering, arts, and mathematics*) (Qu et al., 2021), and iSTEM (*i.e., integrated STEM*) (Struyf et al., 2019), among others.

In the Kyrgyz Republic, STEM education is recognized in the program for the development of education in the Kyrgyz Republic for 2021-2040 (Ministry of Justice of the Kyrgyz Republic, 2021) and the state program for the development of intellectual property and innovation for the Kyrgyz Republic for 2022-2026 (Cabinet of Ministers of the Kyrgyz Republic, 2022). Media documents provided shreds of evidence of STEM education implementation, such as analysis of STEM opportunities in key curricular documents (*e.g., state education standard of school education, basic education curriculum, and subject-specific standards*) and STEM education for girls and out-of-school youth (Girls in Science, n. d.), providing selected-school with STEM laboratory equipment (Abdyrazakova, 2022), and capability building for teachers and school directors (Abduvaitova, 2021). In Naryn and Osh regions specifically, teacher professional development on STEM has been sporadically conducted (Kut Bilim, 2022; Osh State University, 2023).

While there is definitely a lack of studies on various aspects of STEM education in the Kyrgyz Republic, the broader discourse on STEM education identified and elaborated on a number of gaps and challenges. The literature shows that teachers lack a cohesive understanding of STEM education (Kelley & Knowles, 2016), teachers' perceptions of STEM education are pluralistic and differ according to preferences (Lai, 2021), and most teachers are drawn to STEM education models that show STEM beyond the school setting (Dare et al., 2019). Notably, a number of studies outline research frameworks about STEM integration, but translating the same into actual teaching practice remains a challenge, especially for most, if not all, non-STEM schools (Gardner et al., 2019). Most STEM studies did not address key issues of what makes STEM disciplines difficult and challenging to teach (Winberg et al., 2019). Teachers were concerned about their lack of readiness to teach STEM, including contextual issues, pedagogical content knowledge, and teacher efficacy (EL-Deghaidy et al., 2017), resulting from a lack of experience and education, lack of time and resources, and diminished perceived value of the role of STEM (Smith, 2018).

Informed by the works of Shulman (1986, 1987) on pedagogical content knowledge and Bandura (1978, 1997) on teaching efficacy, this study explored the interdependence of knowledge-base in teaching, STEM career awareness, teaching efficacy, attitudes, and STEM teaching readiness among Kyrgyz public school mathematics and science teachers. This study is important and relevant because, firstly, despite the bits and pieces of efforts to streamline STEM education initiated by the government and non-government organizations in the country, more information is needed about its current integration among public schools. Secondly, contextual studies in STEM education such as this study remain relevant, considering that STEM outcomes are somehow associated with students' academic achievement (Terzi & Kirilmazkaya, 2020), and teachers' overall performance in STEM education stimulates students' interest in STEM (Rahman et al., 2021).

STEM Teaching Readiness

Sulaeman et al. (2022) defined STEM teaching readiness as *'the extent of the ability teachers have to take charge of STEM education'* (p. 70). A study by Abdullah et al. (2017) measured three aspects of STEM teaching readiness among 190 Malaysian science and mathematics teachers, including cognitive readiness (*i.e., the readiness of a teacher to think creatively and critically design a concept to solve problems*), affective readiness (*i.e., the continuum of emotional readiness of teachers [positive, neutral, and negative] to carry out their duty*), and behavioral readiness (*i.e., the actual knowledge and skills of teachers in doing something new*) (p. 7). Related thereto, a study by Wu et al. (2022) found that affective readiness directly impacted behavioral intention, while cognitive and behavioral readiness had a significant indirect effect on behavioral intention. The researcher hypothesizes that a significant level of STEM teaching readiness among science and mathematics teachers can result in more frequent integration and teaching of STEM. That being so, developing and strengthening predictors of STEM teaching readiness is imperative.

Knowledge-Base in Teaching

Requisite knowledge, including skills, attitudes, and values associated with STEM disciplines, are contributory elements of STEM teaching competence (Ng, 2019). Along this line, Shulman (1986, 1987) laid the theoretical underpinnings of teachers' pedagogical content knowledge (*referred to as knowledge-base in teaching in this paper*). Pedagogical content knowledge is a

> "second kind of content knowledge, pedagogical knowledge, which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching … include … the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations–in a word, the ways of representing and formulating the subject that make it comprehensible to others … include an understanding what makes the learning of specific topics easy or difficult" (Shulman, 1986, p. 9).

In this study, knowledge-base in teaching was derived from the works of Mishra and Koehler (2006) on technological pedagogical and content knowledge (TPACK) framework. Conceptual definitions of the seven dimensions of TPACK framework are available in their paper (Mishra & Koehler, 2006, p., 1026-1029). Teachers themselves recognize that a deficit in their STEM background knowledge, confidence, and teaching efficacy can hamper students' STEM academic performance (Nadelson et al., 2013).

A study by Dong et al. (2020) revealed that knowledge-base in teaching and teaching efficacy beliefs predict Chinese teachers' perceived STEM teaching challenges. Therefore, the researcher hypothesized the likelihood that science and mathematics teachers' STEM teaching readiness (H_1), teaching efficacy (H_2), and attitudes (H_3) could be predicted by their knowledge-base in teaching.

Teacher Efficacy & Attitudes

Teaching efficacy refers to teachers' views of their ability to handle tasks, obligations, and challenges related to teaching practice (Bandura, 1997). In STEM education, teaching efficacy influences pedagogical preferences and overall professional practice and is associated with content knowledge (Koculu & Topcu, 2021) and the choice of instructional strategies in implementing STEM education (Woo et al., 2018). In this study, two aspects of teaching efficacy were explored, personal teaching efficacy and beliefs (*i.e., one's efficacy and confidence in teaching specific STEM subject*) and teaching outcome expectancy beliefs (*i.e., one's belief that student learning in STEM subject is impacted by one's teaching*) (Friday Institute for Educational Innovation, 2012). Meanwhile, Ajzen (1988) defined attitudes as a *'disposition to respond favorably or unfavorably to an object, person, institution, or event'* (p .4). In this study, attitudes specifically refers to two dimensions, the 21st century learning attitudes (*i.e., teachers' attitudes toward the 21st century learning*), and teacher leadership attitudes (*i.e., teachers' attitudes toward teacher leadership activities*) (Friday Institute for Educational Innovation, 2012).

STEM teaching efficacy shows different patterns of association with a number of variables (Fackler et al., 2021), such as student achievement (Hammack & Ivey, 2017), building instructional repertoire and student engagement (Hollister, 2018), implementation of innovative instructional practice (Deal, 2020), and student interest (Demirkol et al., 2022). Teacher efficacy and beliefs, teacher outcome expectancy beliefs, and the use of instructional strategies vary by discipline (Deal, 2020), therefore addressing issues and concerns related thereto is imperative to ensure a meaningful STEM education (Kareem et al., 2022).

The researcher hypothesizes the likelihood that STEM teaching readiness can be predicted by teaching efficacy (H_4) and attitudes (H_5), and the mediating effect of teaching efficacy between knowledge-base in teaching and STEM teaching readiness (H_9) and between STEM career awareness and STEM teaching readiness (H_{10}), as well as the mediating effect of attitudes between knowledge-base in teaching and STEM teaching readiness (H_{11}) and between STEM career awareness and STEM teaching readiness (H_{12}).

STEM Career Awareness

Another equally important determinant of behavioral intention and behavior is awareness (Stöckli & Dorn, 2021), one's ability to make forced decisions above a chance level of performance, or simply self-reports indicating that one 'consciously sees' a stimulus (Merikle, 1984) or simply everything you experience and seek to understand the objective world described by science (Koch, 2018). STEM career awareness refers to teachers' awareness of STEM careers and where to find resources for further information (Friday Institute for Educational Innovation, 2012). The role of teachers is important in fostering students' STEM career interest and awareness (Cohen et al., 2013); in fact, teachers' awareness of STEM careers impacts students' career choices (Knowles et al., 2018). Connecting lessons to potential careers fosters student motivation to enter

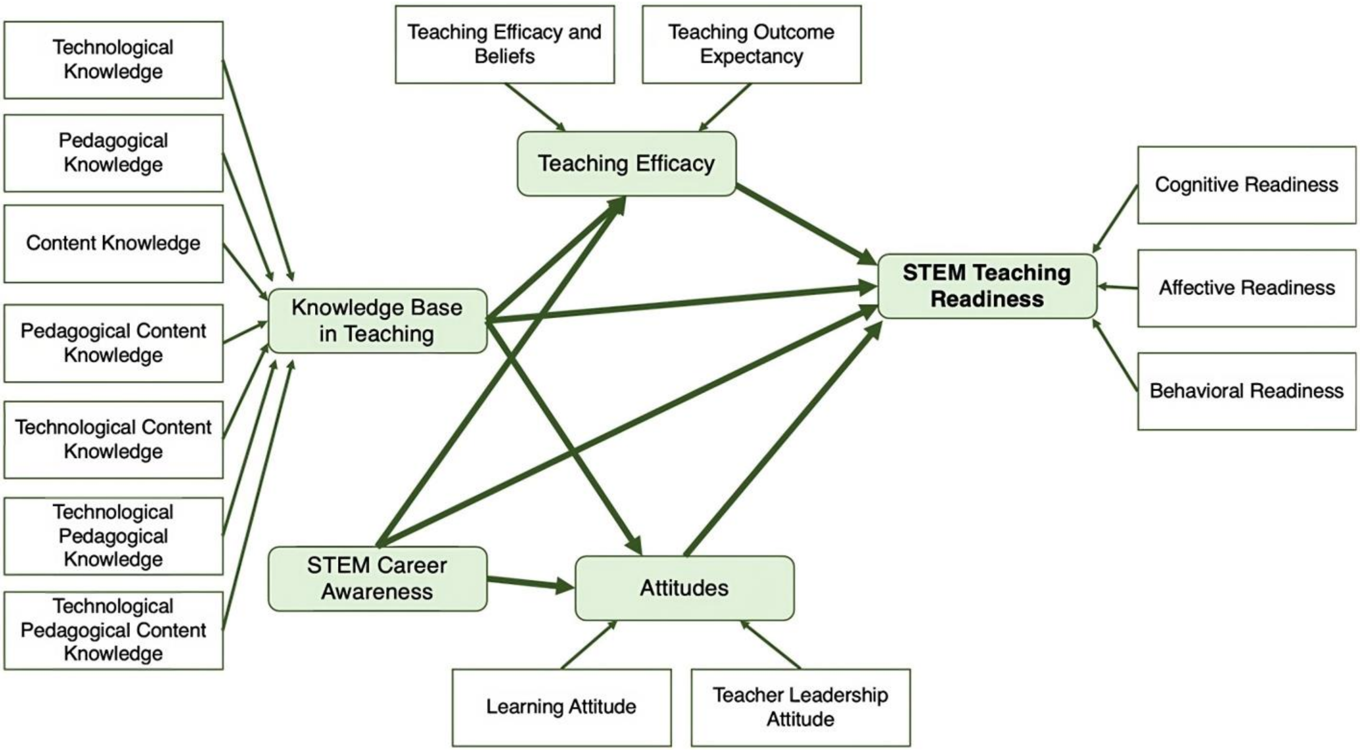

Figure 1. Hypothesized model (Source: Author's own illustration)

STEM careers (Cohen et al., 2013). Nevertheless, there is a limited study that explored teachers' STEM career awareness and its association with STEM teaching.

The researcher hypothesizes the likelihood that STEM teaching readiness (H_6), teaching efficacy (H_7), and attitudes (H_8) can be predicted by STEM career awareness.

Purpose & Hypotheses of the Study

The study explored the interdependence of knowledge-base in teaching, STEM career awareness, teaching efficacy, attitudes, and STEM teaching readiness among Kyrgyz public school science and mathematics teachers. At the onset, the researcher hypothesized the following:

1. Knowledge-base in teaching predicts STEM teaching readiness, teaching efficacy, and attitudes.
2. Teaching efficacy and attitudes predict STEM teaching readiness.
3. STEM career awareness predicts STEM teaching readiness, teaching efficacy, and attitudes.
4. Teaching efficacy and attitudes mediate between knowledge-base in teaching and STEM teaching readiness.
5. Teaching efficacy and attitudes mediate between STEM career awareness and STEM teaching efficacy.

Figure 1 illustrates the hypothesized model assessed in this study. The researcher thinks that understanding the predictors of STEM teaching readiness in context and strategically addressing them is an important initial step toward enhancing STEM education among public schools in the Kyrgyz Republic and elsewhere.

METHODOLOGY

The study followed the quantitative survey research design. Using a print survey, data were collected through intact and convenience sampling of participants from Naryn and Osh regions of the Kyrgyz Republic. Intact sampling because all the science and mathematics teachers at each identified schools were asked to participate in the study; convenience sampling because only science and mathematics teachers present in each identified school at the time of data collection were asked to participate.

Figure 2 shows the study locale in the map of the Kyrgyz Republic.

Figure 2. Map of Kyrgyz Republic indicating study locale (Source: Author's own illustration)

Nevertheless, to ascertain that the analysis yields sufficient statistical power, G*power calculator was used to determine the required minimum number of participants for the study (Faul et al., 2009). With a power=0.83, effect size=0.20, $p<0.05$, and four predictors, the study required a minimum of 69 participants (Hair et al., 2017). 367 public high school science and mathematics teachers, 197 from Naryn and 170 from Osh, aged between 20 and 73 years old (mean age=43.33 years old), participated in the study. 90.00% of the participants were women, and 10.00% were men, whose teaching experience ranged from less than a year to 45 years (mean length of teaching experience=18.72 years). 26.88% of the participants teach biology, 16.40% teach chemistry, 18.82% teach physics, and 37.90% teach mathematics.

Instrument

A 5-point Likert scale questionnaire whose indicators were adapted from literature was used in data collection. Indicators for knowledge-base in teaching were adapted from the works of Schmid et al. (2020). The original instrument is composed of seven sub-dimensions, namely pedagogical knowledge (*seven items*), content knowledge (*six items*), technological knowledge (*seven items*), pedagogical content knowledge (*six items*), technological pedagogical knowledge (*five items*), technological content knowledge (*six items*), and technological pedagogical content knowledge (*five items*) (Schmid et al., 2020, p. 4).

Indicators for teaching efficacy, attitudes, and STEM career awareness were adapted from the teacher efficacy and attitudes toward STEM (T-STEM) survey by Friday Institute for Educational Innovation (2012). The original instrument is composed of teaching efficacy and beliefs (*11 items*), teaching outcome expectancy (*nine items*), the 21st century learning attitudes (*11 items*), teacher leadership attitudes (*six items*), and STEM career awareness (*four items*) (Friday Institute for Educational Innovation, 2012).

Finally, indicators for STEM teaching readiness were adapted from the work of Abdullah et al. (2017). The original instrument is composed of cognitive readiness (*12 items*), behavioral readiness (*10 items*), and affective readiness (*11 items*) (Abdullah et al., 2017, p., 8-11).

Since the indicators were originally in English, it was necessary to translate them into Russian and Kyrgyz languages through participatory collaborative translation.

The participatory collaborative translation uses a team of practitioners whose English language is at a functional level and a local language at advanced academic instead of experts to ensure that indicators preserve their meaning and is sensible in the local context. This translation process is thoroughly described and submitted for publication elsewhere.

Data Analysis

Considering the study's exploratory nature, partial least squares-structural equation modeling using SmartPLS was employed in the data analysis (Ringle et al., 2022). It is *'a nonparametric technique, which makes no distributional assumption and can be estimated with small sample size'* (Ravand & Baghaei, 2016, p. 1). The statistical approach possesses significant rigor as it allows for assessing the instruments' validity and reliability with the actual participants and as specified in the hypothesized model prior to hypotheses testing. The first phase, measurement model assessment, allows one to assess indicator reliability (outer loading ≥0.0708) and consistency (Cronbach's alpha≥0.700), convergent reliability and validity (Djikstra-Henseler's $\rho \geq 0.700$; composite reliability≥0.700; average variance extracted (AVE)≥0.500), discriminant validity (heterotrait-monotrait ratio<1.00), and collinearity (variance inflation factor≤3.3) (Hair et al., 2019; Henseler et al., 2015; Nunnally & Bernstein, 1994). The second phase, structural model assessment, allows one to assess the specific direct effect ($t \geq 1.654$; $p \leq 0.05$), predictive accuracy ($R^2=0.75$ [substantial], $R^2=0.50$ [moderate], $R^2=0.25$ [weak]), effect size ($f^2=0.35$ [substantial], $f^2=0.15$ [moderate], $f^2=0.02$ [weak]), and predictive relevance ($Q^2>0.00$) of the variables under study (Hair et al., 2019; Sarstedt et al., 2019).

RESULTS

Assessment of Measurement Model

Table 1 shows the indicator reliability, consistency, and convergent validity and reliability results. Outer loading of every indicator of each sub-dimension was >0.708, confirming indicator reliability (Hair et al., 2019).

Table 1. Indicator reliability, consistency, & convergent validity & reliability

	OL	α	ρ	CR	AVE
Affective readiness		0.948	0.949	0.959	0.795
AR1	0.897				
AR2	0.907				
AR3	0.891				
AR4	0.900				
AR5	0.881				
AR6	0.872				
Behavioral readiness		0.926	0.937	0.942	0.733
BR1	0.876				
BR2	0.900				
BR3	0.701				
BR4	0.883				
BR5	0.899				
BR6	0.862				
Cognitive readiness		0.954	0.955	0.962	0.785
CR1	0.877				
CR2	0.879				
CR3	0.895				

Table 1 (Continued). Indicator reliability, consistency, & convergent validity & reliability

	OL	α	ρ	CR	AVE
CR4	0.887				
CR5	0.904				
CR6	0.863				
CR7	0.896				
STEM career awareness		0.92	0.920	0.944	0.807
CA1	0.831				
CA2	0.916				
CA3	0.919				
CA4	0.924				
Technological knowledge		0.875	0.878	0.905	0.615
TK1	0.77				
TK2	0.745				
TK3	0.768				
TK4	0.813				
TK5	0.795				
TK6	0.811				
Content knowledge		0.872	0.873	0.907	0.661
CK1	0.822				
CK2	0.823				
CK3	0.811				
CK4	0.813				
CK5	0.796				
Pedagogical knowledge		0.894	0.897	0.917	0.611
PK1	0.775				
PK2	0.768				
PK3	0.844				
PK4	0.778				
PK5	0.807				
PK6	0.757				
PK7	0.738				
Pedagogical content knowledge		0.881	0.881	0.913	0.677
PCK1	0.810				
PCK2	0.828				
PCK3	0.845				
PCK4	0.821				
PCK5	0.809				
TCK		0.899	0.900	0.925	0.712
TCK1	0.835				
TCK2	0.798				
TCK3	0.859				
TCK4	0.868				
TCK5	0.857				
TPK		0.848	0.855	0.898	0.689
TPK1	0.874				
TPK2	0.858				
TPK3	0.754				
TPK4	0.829				
TPCK		0.894	0.896	0.922	0.702
TPCK1	0.823				
TPCK2	0.834				
TPCK3	0.881				
TPCK4	0.847				
TPCK5	0.802				
Learning attitudes		0.932	0.935	0.942	0.621
LA2	0.770				
LA3	0.807				
LA4	0.760				
LA5	0.829				
LA6	0.759				
LA7	0.785				
LA8	0.788				
LA9	0.807				
LA10	0.782				
LA11	0.790				
Teacher leadership attitudes		0.901	0.905	0.926	0.716
TLA1	0.823				
TLA2	0.799				
TLA3	0.870				
TLA4	0.852				
TLA5	0.884				
Teaching efficacy & beliefs		0.925	0.928	0.938	0.626
TEB1	0.766				
TEB2	0.836				
TEB3	0.821				
TEB4	0.787				
TEB5	0.799				
TEB7	0.745				
TEB8	0.795				
TEB9	0.823				
TEB10	0.742				
Teaching outcome expectancy		0.877	0.880	0.905	0.576
TOE1	0.787				
TOE2	0.755				
TOE3	0.736				
TOE4	0.782				
TOE6	0.733				
TOE7	0.781				
TOE8	0.734				

Note. OL: Outer loading; α: Cronbach's alpha; ρ: Dijkstra-Henseler's ρ; CR: Composite reliability; TCK: Technological content knowledge; TPK: Technological pedagogical knowledge; & TPCK: Technological pedagogical content knowledge

Cronbach's alpha of each sub-dimension is ≥ 0.700 (*adequate for all sub-dimensions of knowledge-base in teaching; bare minimum for teaching efficacy and beliefs, learning attitudes, teacher leadership attitudes, and STEM career awareness, and adequate for teaching outcome expectancy; bare minimum for affective and behavioral readiness, and desirable for cognitive readiness*), confirming indicator consistency (Nunnally & Bernstein, 1994).

All Djikstra-Henseler's ρ and composite reliability of all sub-dimensions are >0.700, and AVE are >0.500, ascertaining convergent reliability and validity (Hair et al., 2019).

Table 2 shows that all heterotrait-monotrait ratio between and among the sub-dimensions of variables under study are <1.00, confirming discriminant validity (Hair et al., 2019).

Table 3 shows that all outer and inner variance inflation factors (VIF) are <3.3 stringent upper threshold confirming that there are no collinearity issues among the variables under study (Hair et al., 2019).

Table 2. Heterotrait-monotrait ratio

	AR	BR	CA	CK	CR	LA	PCK	PK	TCK	TEB	TK	TLA	TOE	TPCK
BR	0.888													
CA	0.772	0.650												
CK	0.328	0.348	0.404											
CR	0.836	0.720	0.905	0.446										
LA	0.347	0.414	0.343	0.397	0.377									
PCK	0.425	0.390	0.515	0.813	0.559	0.512								
PK	0.382	0.390	0.410	0.649	0.478	0.553	0.749							
TCK	0.469	0.450	0.609	0.716	0.658	0.415	0.796	0.624						
TEB	0.409	0.444	0.469	0.790	0.507	0.566	0.803	0.671	0.774					
TK	0.522	0.497	0.520	0.624	0.593	0.413	0.618	0.525	0.701	0.523				
TLA	0.404	0.479	0.38	0.353	0.400	0.760	0.394	0.480	0.354	0.462	0.317			
TOE	0.377	0.469	0.338	0.44	0.371	0.754	0.483	0.579	0.446	0.666	0.376	0.724		
TPCK	0.576	0.603	0.599	0.635	0.643	0.545	0.733	0.664	0.801	0.802	0.647	0.527	0.526	
TPK	0.503	0.533	0.588	0.568	0.600	0.478	0.716	0.630	0.83	0.750	0.655	0.448	0.535	0.905

Note. AR: Affective readiness; BR: Behavioral readiness; CA: STEM career awareness; CK: Content knowledge; CR: Cognitive readiness; LA: Learning attitudes; PCK: Pedagogical content knowledge; PK: Pedagogical knowledge; TCK: Technological content knowledge; TEB: teaching efficacy & beliefs; TK: Technological knowledge; TLA: Teacher leadership attitudes; TOE: Teaching outcome expectancy; & TPCK: Technological pedagogical content knowledge

Table 3. Collinearity, predictive accuracy, predictive relevance, & effect size

	Inner VIF (first stage)			Outer VIF (second stage)	R^2	Q^2	f^2		
	Readiness	Attitudes	TE				Readiness	Attitudes	TE
Readiness					0.762	0.567			
AR				4.885					
BR				3.366					
CR				2.741					
Attitudes	1.548*				0.317	0.253	0.005		
LA	2.673			1.965					
TLA	2.388			1.965					
TE	3.255*				0.675	0.461	0.004		
TEB	4.250			1.562					
TOE	2.622			1.562					
KB	3.800*	1.490*	1.490*				0.071	0.277	1.488
TK	2.015	1.883	1.883	1.842					
CK	2.801	2.374	2.374	2.358					
PK	2.199	2.014	2.014	2.014					
PCK	3.288	3.102	3.102	3.088					
TCK	3.460	3.294	3.294	3.199					
TPK	3.330	3.239	3.239	3.227					
TPCK	3.912	3.363	3.363	3.289					
CA-1	1.505*	1.490*	1.490*						
CA	1.631	1.593	1.593				1.437	0.003	0.005

Note. AR: Affective readiness; BR: Behavioral readiness; CA: STEM career awareness; CA-1: Career awareness; CK: Content knowledge; CR: Cognitive readiness; KB: Knowledge-base; LA: Learning attitudes; PCK: Pedagogical content knowledge; PK: Pedagogical knowledge; TCK: Technological content knowledge; TE: Teaching efficacy; TEB: teaching efficacy & beliefs; TK: Technological knowledge; TLA: Teacher leadership attitudes; TOE: Teaching outcome expectancy; TPCK: Technological pedagogical content knowledge; & *Inner VIF (second stage);

Assessment of Structural Model

Table 4 shows the specific direct and indirect effects of the variables under study.

Results revealed that STEM teaching readiness was predicted by knowledge-based in teaching (β=0.253; t=4.461; p=0.001) and STEM career awareness (β=0.717; t=20.701; p=0.001), but not by teaching efficacy (β=-0.057; t=1.158; p=0.123) and attitudes (β=0.041; t=1.102; p=0.135). Moreover, teaching efficacy (β=0.848; t=31.122; p=0.001) and attitudes (β=0.530; t=7.697; p=0.001) were predicted by knowledge-base in teaching but not by STEM career awareness.

Finally, teaching efficacy and attitudes did not mediate between knowledge-base in teaching and STEM teaching readiness and between STEM career awareness and STEM teaching readiness (Hair et al., 2019). The same findings were confirmed upon examining the confidence intervals bias corrected (Sarstedt et al., 2019).

STEM teaching readiness (R^2=0.762) possessed substantial predictive accuracy, teaching efficacy (R^2=0.675) had moderate predictive accuracy, while attitudes (R^2=0.317) had a weak predictive accuracy

Table 4. Specific direct & indirect effects

Hypotheses	β	SM	SD	t	p	CI bias corrected		D
						5.00%	95.00%	
Knowledge-base in teaching→STEM TR	0.253	0.258	0.057	4.461	0.001	0.160	0.347	S
Knowledge-base in teaching→Teaching efficacy	0.848	0.849	0.027	31.122	0.001	0.798	0.889	S
Knowledge-base in teaching→Attitudes	0.530	0.536	0.069	7.697	0.001	0.402	0.634	S
Teaching efficacy→STEM TR	-0.057	-0.058	0.049	1.158	0.123	-0.134	0.027	NS
Attitudes→STEM TR	0.041	0.040	0.037	1.102	0.135	-0.016	0.107	NS
STEM career awareness→STEM TR	0.717	0.716	0.035	20.701	0.001	0.658	0.771	S
STEM career awareness→Teaching efficacy	-0.048	-0.047	0.039	1.224	0.111	-0.112	0.018	NS
STEM career awareness→Attitudes	0.055	0.051	0.061	0.892	0.186	-0.041	0.159	NS
Knowledge-base in teaching→Teaching efficacy→STEM TR	-0.048	-0.049	0.042	1.159	0.123	-0.114	0.024	NS
STEM career awareness→Teaching efficacy→STEM TR	0.003	0.003	0.004	0.766	0.222	-0.001	0.012	NS
Knowledge-base in teaching→Attitudes→STEM TR	0.022	0.021	0.02	1.078	0.140	-0.008	0.058	NS
STEM career awareness→Attitudes→STEM TR	0.002	0.002	0.004	0.564	0.287	-0.001	0.015	NS

Note. SM: Sample mean; SD: Standard deviation; CI: Confidence interval; D: Decision; S: Supported; NS: Not supported; & TR: teaching readiness

(Hair et al., 2019). Knowledge-base in teaching had a substantial effect size on teaching efficacy, a moderate effect size on attitudes, and a small effect size on STEM teaching readiness. In addition, STEM career awareness had a substantial effect on STEM teaching readiness and a small effect on teaching efficacy and attitudes. Finally, teaching efficacy and attitudes had a small effect on STEM teaching readiness. With $Q^2>0.001$, STEM teaching readiness ($Q^2=0.567$), teaching efficacy ($Q^2=0.461$), and attitudes ($Q^2=0.253$) possessed predictive relevance, as modeled in the study(Hair et al., 2019).

DISCUSSIONS AND IMPLICATIONS

Knowledge-Base in Teaching, STEM Career Awareness, & Teaching Readiness

The findings of this study showed that STEM teaching readiness could be influenced by knowledge-base in teaching and STEM career awareness. That being so, enhancing science and mathematics teachers' knowledge-base in teaching and STEM career awareness may increase STEM teaching readiness. Among the dimensions of STEM teaching readiness explored in this study include

(a) affective readiness manifested through satisfaction and enjoyment in STEM teaching, comfortable in implementing STEM education, excitement with student interaction, untroubled with added teaching preparation, and comfortable in bringing real-life examples in STEM teaching (Abdullah et al., 2017, p. 9-10),

(b) behavioral readiness manifested by following existing recommendations for STEM education implementation, conducting activities that increase students' motivation, referring to and analyzing students' performance, doing rigorous preparations and confidence in implementing STEM, and readiness to attend STEM teacher professional development (Abdullah et al., 2017, p. 10-11), and

(c) cognitive readiness manifested by understanding the objectives and goals of STEM education, teachers' roles in STEM, the STEM education curriculum being developed, the scope of STEM education in high school, knowing different STEM teaching approaches, resources, and ways of integrating daily life problems in teaching (Abdullah et al., 2017, p. 8-9).

Meanwhile, the knowledge-base in teaching referred to in this study was associated with the seven dimensions of TPACK framework. Operationally, these dimensions are defined in **Table 5**.

STEM career awareness can be manifested by knowing where to learn more, finding resources for teaching students, and directing students and parents to find information about STEM careers.

Boosting the above-enumerated indicators of knowledge-base in teaching and STEM career awareness through a teacher professional development and by integrating technology and the nature of discipline may likely impact STEM teaching ability (Faikhamta et al., 2020; Niess, 2005), consequently increasing STEM teaching readiness. Unsurprisingly, teachers' knowledge-base in teaching is expectedly diverse as a result of their beliefs, backgrounds, and teaching contexts (Vossen et al., 2019), resulting in differences in instructional practices, and perceived challenges (Dong et al., 2020). Therefore it is imperative to enhance teachers' awareness, growth, and knowledge-base in STEM teaching throughout their careers to strengthen their ability to teach STEM (Coomes et al., 2022). STEM career awareness can be strengthened by outreach activities (e.g., interacting with leading personalities in STEM and research), broadening the capacity to teach STEM through real-world applications (Aslam et al., 2018), improving motivations and attitudes toward STEM (Vennix et al., 2018), and increasing perceived ability and intention to implement STEM (Adams et al., 2014).

Table 5. Operational definition of knowledge-base in teaching dimensions (Schmid et al., 2020)

D	Operational definitions
TK	Ability to learn, keep up, & play around with new technologies, knowing a lot of and having technical skills & sufficient opportunities to work with different technologies
CK	Sufficient knowledge in & various strategies to develop an understanding of science/mathematics, capability in scientific/mathematical ways of thinking, & knowing history & important theories & recent developments in science/mathematics
PK	Knowing how to assess students' learning in multiple ways, adapt a wide range of teaching styles to students' prior knowledge & different types of learners, common student learning difficulties, & maintain effective classroom management
PCK	Knowing how to select effective teaching approaches, develop appropriate tasks & exercises, evaluate students' performance, explain essential content, identify students' difficulties, & give appropriate interventions in science/mathematics
TCK	Knowing relevant old & new technologies for understanding & doing science/mathematics, knowing how technological development have changed science/mathematics, & using technologies to participate in science/mathematics discourse
TPK	Being able to think critically & choose technologies that can enhance teaching & learning
TPCK	Being able to teach & enhance lessons by employing strategies that combine content, technology, & pedagogy, & provide leadership in helping others to use the same at school

Note. D: Dimensions; TK: Technological knowledge; CK: Content knowledge; PK: Pedagogical knowledge; PCK: Pedagogical content knowledge; TCK: Technological content knowledge; TPK: Technological pedagogical knowledge; & TPCK: Technological pedagogical content knowledge

Teaching Efficacy, Attitude, & STEM Teaching

The findings of the study showed that STEM teaching readiness was not predicted by teaching efficacy and attitudes, but both teaching efficacy and attitudes were predicted by knowledge-base in teaching. These findings may have more meaning that the survey data could not explain. Nevertheless, the literature is almost consistent about the important role of teaching efficacy and attitudes in readiness (Stephen & Tawfik, 2022), student engagement (Upadhyaya, 2019), and teaching practice (Chen et al., 2022). Two aspects of teaching efficacy were explored in this study; teaching efficacy and beliefs manifested as one's belief in continually improving teaching practice, knowing the steps to teach effectively, confidence in teaching and explaining why experiments work, helping weak students, and inviting a colleague to evaluate one's teaching; and teaching outcome expectancy demonstrated as one's belief that students' performance is associated with teaching performance and a feeling of responsibility for students' learning (Friday Institute for Educational Innovation, 2012).

Meanwhile, attitudes in this study refer to the 21st century learning attitudes shown as leading others to accomplish goals, encouraging others to do their best, producing high-quality work, respecting individual differences, helping others, including other's perspectives, in making decisions, making changes when things do not go as planes, setting own goals, managing time wisely, prioritization, and working with students from different backgrounds; and teacher leadership attitudes manifested as taking responsibility for all students' learning, conveying the importance of learning to students, using a variety of assessments to assess progress, creating opportunities for students to express themselves freely and develop responsibility, and empowering students (Friday Institute for Educational Innovation, 2012). DeChenne (2015) found that teaching experience, school teaching climate, and professional development are important sources of teaching efficacy. Buechel (2021), Seals et al. (2017), Smith (2018) revealed that professional development through a collaborative community of practice, integration of hands-on practice, access to curriculum materials, as well as having supportive and collaborative colleagues significantly increases feelings of teaching efficacy.

CONCLUSIONS

This study explored the interdependence of knowledge-base in teaching STEM career awareness, teaching efficacy, attitudes, and STEM teaching readiness among 367 public high school science and mathematics teachers from Osh and Naryn regions of Kyrgyz Republic. PLS-SEM analysis of data collected through a print survey confirmed that STEM teaching readiness could be predicted by knowledge-base in teaching and STEM career awareness but not by teaching efficacy and attitudes. Moreover, teaching efficacy and attitudes could also be predicted by knowledge-base in teaching but not by STEM career awareness. Lastly, teaching efficacy and attitudes did not mediate between knowledge-base in teaching and STEM teaching readiness and between STEM career awareness and STEM teaching readiness.

Limitations and Recommendations

This study is exploratory in nature. While the use of PLS-SEM through SmartPLS in data analysis is robust, and the number of participants was sufficient, it may be necessary to validate the findings of this study with equally or more rigorous statistical analysis and tools, using other research designs, and with a greater number of participants. The participants in this study were public high school science and mathematics teachers; it may be necessary to include teachers from other related STEM disciplines, such as information technology and geography teachers. A number of studies reported direct and indirect effects of demographic variables on the variables under study (Choi & Hong, 2022); examining the same through another study may be necessary. Further, the model assessed in this study is a hierarchical component model; that is, at the second-order level, it may be interesting to explore the specific direct and indirect effects of the first-order variables under study.

Recommendations and Way Forward

Internationally, STEM education advocacy is not completely new. Nevertheless, it may be necessary to build and strengthen existing STEM education infrastructure in schools, including passing legislation and developing a policy framework for STEM education in the Kyrgyz Republic.

Extant literature revealed the lack of cohesive understanding and misconceptions of teachers about STEM, including content and technology-use difficulties (Kelley & Knowles, 2016; Vichaidit & Faikhamta, 2019). A carefully designed, locally-relevant, and context-specific teacher professional development focused on the variables under study is imperative to improve conceptions (Ring et al., 2017), reduce resistance (Sirakaya & Alsancak Sirakaya, 2022), and transform knowledge-base in teaching (Niwat, 2012), creating a holistic STEM teacher (Seery et al., 2018).

There is a rich literature on STEM education professional development approaches, such as active engagement with research-based pedagogies (Milner-Bolotin, 2018), use of observation-discussion-reflection framework (Huang et al., 2022), and use of digital media (Wolfe, 2019).

Additionally, Zhong et al. (2022) pointed out

(a) the need to develop a consensus on STEM terminologies that accounts for contextual factors,

(b) move forward with all the levels of STEM education and reach a standard thinking degree,

(c) establish multi-party collaborative service mechanism, and

(d) establish school culture and environment that supports STEM education.

Finally, Liu (2020) acknowledged six issues delimiting STEM teaching that must be addressed, including

(a) disciplinary integration,

(b) emphasizing disciplinary knowledge,

(c) equitable discipline representations,

(d) the need for more mathematics,

(e) advancing collaboration, and

(f) the need to address inequality.

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