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STEM Pedagogical Content Knowledge Scale (STEMPCK): A Validity and Reliability Study

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STEM Pedagogical Content Knowledge (STEMPCK) Scale: A Validity and Reliability Study

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Abstract

The aim of this study was to develop the STEM Pedagogical Content Knowledge Scale (STEMPCK Scale). Exploratory and confirmatory factor analyses were conducted to examine the structural validity of the scale. Exploratory factor analysis of the scale was conducted using data from 443 preservice teachers who were studying to become science teachers, preschool teachers, elementary school teachers, and mathematics teachers. The confirmatory factor analysis of the scale was conducted using data from 212 students who were enrolled in the same departments. The scale was administered to 655 preservice teachers in total. To determine the reliability of the scale, the Cronbach's Alpha internal consistency coefficient, the corrected total item correlation, and the significance of the differences between the item averages of the top 27% and bottom 27% were examined by *t*-test. According to the results obtained, the STEMPCK Scale consists of six factors: 21st-Century Skills, Pedagogical Knowledge, Mathematics, Science, Engineering, and Technology. The scale included 56 items. The Cronbach's Alpha values of the factors ranged from 0.878 to 0.90, and the corrected item total score correlations ranged from 0.306 to 0.895. The results of the *t*-test showed that all the differences between the mean scores of the top 27% and bottom 27% on the items were significant. The results of the analyses indicate that the instrument has reasonable internal consistency and that the theoretical structure was supported by empirical data. These results indicate that the STEMPCK Scale is an appropriate tool for measuring preservice teachers' STEM pedagogical content knowledge. Implications and suggestions for further studies are included.

Keywords: Pedagogical content knowledge; Reliability; STEM; Validity

Scientific and technological progress requires workers to have different skills than in the past. In addition to foundational skills like literacy and numeracy, they need competencies such as problem solving, critical thinking, creativity, and collaboration and character qualities such as curiosity. To teach the skills that meet the needs of a 21st-century marketplace, countries have made reforms in their educational systems (Drew, 2011). Science, technology, engineering, and mathematics (STEM) lie at the heart of these reform movements. Through the integration of science, technology, engineering, and mathematics, students would be able to study the challenges that arise in today's world such as energy shortages, environmental problems, and health problems (Bybee, 2010). Students fully equipped with STEM knowledge will be able to identify, apply, and integrate its concepts to understand complex problems and generate solutions to solve those problems (Meng, Idris, Eu, & Daud, 2013). Successful integration of STEM largely "depends on whether teachers develop a solid understanding of subject matter and conceptualize connections among subjects" (Pang & Good, 2000, p. 77). Many teachers have holes in their subject content knowledge; therefore, asking teachers to teach another subject may create new knowledge gaps, challenges, and difficulties (Stinson, Harkness, Meyer, & Stallworth, 2009).

To successfully implement STEM education in schools, teachers should understand what STEM means and should be equipped with STEM-related skills and knowledge of STEM. Teachers should apply effective teaching methods and techniques in their classroom to support students' learning of STEM areas (Lichtenberger & George-Jackson, 2013). Furthermore, teachers should acknowledge students' success in STEM-related fields (Beier & Rittmayer, 2008). It is important for teachers to have strong content and pedagogical knowledge in STEM (Kennedy, Ahn, & Choi, 2008).

In the STEM education research literature, there is a no clear agreement about the concept of pedagogical content knowledge (PCK) and content knowledge for teaching. In spite of this lack of agreement, researchers use Shulman's model as a basis for research about teachers' PCK. According to Shulman (1986), several domains of knowledge influence how teachers teach. These domains are: content knowledge, general pedagogical knowledge (i.e., knowledge of strategies for classroom management), curriculum knowledge, PCK, knowledge of learners and their characteristics, knowledge of context (i.e., classroom), and knowledge the purposes and values of education (Cochran, DeRuiter, & King, 1993; Hume & Berry, 2011; Shulman, 1986). During the years, other researchers (Appleton, 2003; Cochran et al., 1993; Magnusson, Krajcik, & Borko, 1999) have built on or challenged Shulman's approach by suggesting different views of PCK. From another point of view, PCK has its own unique identifiers (Magnusson et al., 1999). Based on these models, PCK is a transformation of knowledge from other knowledge categories (e.g., orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science, and knowledge and beliefs about instructional strategies for teaching science; Magnusson et al., 1999).

Numerous methods of measuring teachers' PCK have been developed since Shulman introduced it (Baxter & Lederman, 1999): the lesson planning method (developed by van der Valk and Broekman, 1999), the use of metaphors, the use of "classroom window" cases (developed by Loughran, Milroy, Berry, Gunstone, and Mulhall, 2001), expert–novice studies, interviews, classroom observations, and teacher focus groups (Abell, 2007; Baxter & Lederman, 1999; Hume & Berry, 2011; Loughran, Berry, & Mulhall, 2012). All these techniques are divided into three categories: (1) convergent and inferential techniques; (2) concept mapping, card sorts, and pictorial representations; and (3) multimethod evaluations (Baxter & Lederman, 1999).

In a review of research published in science education, different tools were used for gathering information about teacher practices, content knowledge, and PCK in STEM education interventions (Minner & Martinez, 2013; Minner, Martinez, & Freeman, 2013). These instruments are observation protocols such as the Instructional Strategies Classroom Observation Protocol (ISCOP), the Lesson Flow Classroom Observation Protocol (LFCPO), the Science Teacher Inquiry Rubric (STIR), Assessment of the Facilitation of Mathematizing (AFM), and Early Mathematics Classroom Observation (EMCO); scoring rubrics such as Transforming Instruction by Design in Earth Science (TIDES) and Scoop Notebook (Scoop); surveys such as the Indiana Mathematics Beliefs Scale (IMBS) and the Science Teaching Efficacy Belief Instrument (STEBI); protocols such

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as Danielson's Framework for Teaching Domains (FFT); and interviews such as Views of Nature of Science Form C (VNOS-C; Minner & Martinez, 2013; Minner et al., 2013). Most instruments have been developed to assess students' knowledge and then adapted for teachers (Minner & Martinez, 2013). Furthermore, it seems that current instruments are limited to assessing teachers' PCK in STEM (STEMPCK) and that more effort needs to be made to develop new instruments for STEM educational interventions (Benuzzi, 2015; Hudson, English, Dawes, King, & Baker, 2015; Rogers, Winship, & Sun, 2016; Stohlmann, Moore, & Roehrig, 2012). This study will hopefully begin to fill that gap by not only describing STEMPCK but also explaining how these areas will be assessed through one instrument.

To effectively integrate STEM education, teachers should adequately build STEMPCK. STEMPCK is a combination of different categories: STEM content knowledge, STEM integration knowledge, pedagogical knowledge, 21st-century skills knowledge, and context knowledge (Appleton, 1995, 2003; Avery, 2009; Ball, Thames, & Phelps, 2008; Benuzzi, 2015; Custer & Daugherty, 2009; Eckman, Williams, & Silver-Thorn, 2016; Eilks & Markic, 2011; Epstein & Miller, 2011; Harris & Hofer, 2011; Hill, Rowan, & Ball, 2005; Hudson et al., 2015; C. A. Lee & Houseal, 2003; K.-T. Lee & Nason, 2012; Nadelson, Seifert, Moll, & Coats, 2012; National Research Council, 2000; President's Council of Advisors on Science and Technology [PCAST], 2010; Rogers et al., 2016; Stohlmann et al., 2012; Shulman, 1986; Wilson, 2011; Wang, Moore, Roehrig, & Park, 2011).

Content knowledge is defined as "the amount and organization of knowledge per se in the mind of the teacher" (Shulman, 1986, p. 9). This knowledge includes different components including knowledge of concepts (including principles and definitions), theories, ideas, organizational frameworks, knowledge of evidence and proof, and the knowledge construction process (Shulman, 1986). Teachers who have strong knowledge and skills in the STEM disciplines can easily integrate STEM education into practice and develop effective STEM teaching strategies (Abell, 2007; Ball et al., 2008; Bukova-Güzel, Cantürk-Günhan, Kula, Özgür, & Elçí, 2013; Nadelson et al., 2012; PCAST, 2010). Teachers' effectiveness in teaching STEM subjects is related to their competence in the individual subjects (Eckman et al., 2016; C. A. Lee & Houseal, 2003). Teachers of STEM disciplines must have a conceptual understanding of how the STEM subjects are interactive and adaptable (Ostler, 2012). Besides having a broad knowledge base of STEM content, teachers must witness advanced integrated pedagogical models to be able to integrate these practices into their classroom teaching (Ostler, 2012). Furthermore, STEM integration knowledge is also related to STEMPCK and PCK. Teachers with strong STEMPCK do not avoid teaching STEM subjects and integrating STEM disciplines in the classroom (Yıldırım, 2016; Wang et al., 2011).

Pedagogical knowledge refers to knowledge of teaching methods, knowledge of classroom assessment, and knowledge of learning processes (Shulman, 1986). Teachers with deep pedagogical knowledge understand how students construct knowledge; understand cognitive, social, and developmental theories of learning; understand how such theories apply to students in their classroom; and are aware of what is going on in all parts of the classroom and are able to handle several classroom events. In short, pedagogical knowledge includes all issues related to student learning, classroom management, knowledge of assessments, knowledge of student characteristics, and lesson plan development and implementation (Yusof, Zakaria, & Maat, 2012; Briscoe & Peters, 1997; Shulman, 1986).

Twenty-first-century skills knowledge describes the skills and knowledge that all students must master to succeed in life and work. Twenty-first-century skills should be taught in conjunction with core academic knowledge (such as music, mathematics, and science) and other essential skills, such as learning and innovation skills (including critical thinking and problem solving, creativity and innovation, communication and collaboration, visual literacy, scientific and numerical literacy, cross-disciplinary thinking, and basic literacy); information, media, and technology skills (including information literacy; media literacy; and information, communications, and technology literacy); and life and career skills (including flexibility and adaptability, initiative and self-direction, social and cross-cultural skills, productivity and accountability, and leadership and responsibility; Binkley et al., 2012; Voogt & Roblin, 2010).

Context knowledge refers to knowledge of internal and external resources. Internal sources include reflection on personal experiences of teaching, and external sources include subject-matter knowledge and government rules about education and policies (Barnett & Hodson, 2001). Context defines the environment for teaching and learning that includes content. A classroom, the characteristics of the region, the culture of the school, students' backgrounds, the province of the school, and the region of the school also affect the effectiveness and quality of STEM education (Harris & Hofer, 2011; Shulman, 1986; Yusof et al., 2012).

Up to this point, we have summarized the research on teachers' PCK and proposed a new model, the STEMPCK model, to teach and train in-service and preservice teachers. Based on an intensive literature review and interviews with preservice teachers and engineering students, we hypothesized that STEMPCK has different categories: content knowledge, integration knowledge, pedagogical knowledge, 21st-century skills knowledge, and context knowledge. Although there have been many studies conducted to evaluate STEM teachers' beliefs and to develop teachers' experiences in the classroom while integrating STEM curricula, there is no single instrument to evaluate teachers' STEMPCK. Because it is difficult and expensive to score open-ended questions, concept maps, and comments on videotaped lessons, there is a need for new instruments to evaluate teachers' STEMPCK. Therefore, in this study, we developed a paper-and-pencil test: the STEM Pedagogical Content Knowledge Scale (STEMPCK Scale) for preservice teachers. We believe that this study makes an important contribution to research on STEMPCK.

Methods

In this study, an instrument, the STEMPCK Scale, was developed to determine preservice teachers' STEMPCK.

Participants

The study was conducted during the fall semester of 2016 in a public university located in the eastern part of Turkey. The participants were preservice teachers from different departments, including Science Education, Mathematics Education, Early Childhood Education, and Elementary School Education.

Research Group

Two different groups of preservice teachers participated in this study. The first group consisted of 443 preservice teachers who were studying in the Science Education, Mathematics Education,

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Early Childhood Education, and Elementary School Education departments. The second group consisted of 212 preservice teachers who were studying in the same departments. The exploratory factor analysis of the developed scale was conducted using data from the first group, and the confirmatory factor analysis was conducted using data from the second group. Because repeating the study and either redoing the exploratory factor analysis or conducting a confirmatory factor analysis after an exploratory factor analysis in the first sample or conducting two successive confirmatory factor analyses would not validate the supposed structure, different samples were used in the study. Frequency and percentage distributions of the preservice teachers in the first and second groups by their departments are shown in Table 1.

Table 1 shows that 11.29% of the participants in Study Group 1 were preservice science teachers, 18.06% were preservice mathematics teachers, 27.99% were preservice early childhood teachers, and 42.95% were preservice elementary school teachers. In Study Group 2, 16.51% of the participants were preservice science teachers, 19.81% were preservice mathematics teachers, 25.94% were preservice early childhood teachers, and 37.74% were preservice elementary school teachers. The distribution of preservice teachers by grade level is shown in Table 2. Table 2 shows that 33.74% of the preservice teachers were sophomore students, 35.73% were juniors, and 30.53% were seniors.

A sample consisting of 655 preservice teachers was selected for the exploratory and confirmatory factor analyses of the STEMPCK Scale. Exploratory and confirmatory factor analyses of the scale were performed using this sample. According to Comrey and Lee (1992), because this scale's sample group is 655, it has a "very good" rating (p. 217). Additionally, Tavşancıl (2002) also points out that to carry out factor analysis for a scale, the sample should be five to 10 times larger than the number of items. In this study, the sample is five times larger than the number of items.

Development of the STEMPCK Scale

In the process of developing an instrument to measure teachers' STEMPCK, five stages were involved.

Table 1
Frequency and Percentage Distribution of Preservice Teachers in Study Group by Department and Major

	Study Group 1		Study Group 2	
Department and major	*f*	%	*f*	%
Department of Mathematics and Science Education				
Science Education	50	11.29	35	16.51
Mathematics Education	80	18.06	42	19.81
Department of Primary Education				
Early Childhood Education	124	27.99	55	25.94
Elementary School Education	189	42.66	80	37.74
Total	443	100	212	100

Table 2
Frequency and Percentage Distribution of Preservice Teachers by Grade Level (*N* = 655)

Major	*f*	%
Sophomore		
Science Education	47	7.18
Mathematics Education	48	7.33
Early Childhood Education	55	8.40
Elementary School Education	71	10.84
Total	221	33.74
Junior		
Science Education	21	3.21
Mathematics Education	40	6.11
Early Childhood Education	60	9.16
Elementary School Education	113	17.25
Total	234	35.73
Senior		
Science Education	17	2.60
Mathematics Education	37	5.65
Early Childhood Education	61	9.31
Elementary School Education	85	12.98
Total	200	30.53

Stage 1. To develop the STEMPCK Scale's items, interviews were conducted with 40 students from different education majors, including Science Education, Mathematics Education, Early Childhood Education, and Elementary School Education, and 17 students from the Computer Science department. In the interviews, students were asked open-ended questions regarding what they thought about content knowledge, STEM content knowledge, PCK, 21st-century skills, STEM integration knowledge, and STEM integration.

Stage 2. Before the scale was developed, an extensive review of the literature was conducted. This literature review included studies focused on the STEM disciplines; teaching the STEM disciplines; and scales to determine teachers' PCK, technological PCK, and engineering PCK (e.g., Aksu, Metin, & Konyalıoğlu, 2014; Bukova-Güzel et al., 2013; Brenneman, 2011; Campbell, Abd-Hamid, & Chapman, 2010; Enochs, Smith, & Huinker, 2000; Faber et al., 2013; Halim, Mohd Meerah, Zakaria, Syed Abdullah, & Tambychik, 2012; Kelleys & Knowles, 2016; Kiray, 2016; Kloosterman & Stage, 1992; Koehler et al., 2011; Önal, 2016; Ryang, 2014; Schmidt et al., 2009; Unfried, Faber, Stanhope, & Wiebe, 2015; Viiri, 2003; Yıldırım & Selvi, 2015, Yusof et al., 2012).

Stage 3. The knowledge gained from the literature and the data gathered from interviews

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were used to develop a draft scale that included 72 items about STEMPCK. These items were placed under the themes: STEM content knowledge, STEM integration knowledge, pedagogical knowledge, 21st-century skills knowledge, and context knowledge.

Stage 4. Afterwards, to ensure content validity of the STEMPCK Scale, the draft scale was sent to six experts. Four of those experts were in the STEM field; one was in the Evaluation, Measurement, and Research Design department; and the last was an expert in PCK. The experts were asked to examine items regarding to their relevance to content coverage, understandability, and consistency among items. Experts' suggestions about clarity of items were taken into consideration, and any necessary changes were made.

Stage 5. The final version of the 72-item draft scale was administered to 60 preservice teachers. Preservice teachers checked the comprehensibility of all developed items. Then, the items on the scale were rearranged based on statistical results. The last version, consisting of 56 items that were rated on a 5-point scale, was administered to 655 preservice teachers. Preservice teachers' responses were analyzed using SPSS Statistics (Version 17) and LISREL (Version 8).

Factor Analysis of the STEMPCK Scale and Reliability Analyses

To conduct a descriptive factor analysis of the scale, the final draft of the STEMPCK instrument was administered to 433 preservice teachers. The confirmatory factor analysis of the scale was performed using data from 212 preservice teachers. The validity and reliability analyses of the scale were calculated using SPSS Statistics (Version 17) and LISREL (Version 8). The results of the exploratory and confirmatory factor analyses of the STEMPCK Scale are explained below.

Results of the exploratory factor analysis. Factor analysis is a collection of methods used to examine how underlying factors influence the variable (Büyüköztürk, 2006). There are two types of factor analyses: exploratory factor analysis and confirmatory factor analysis. Exploratory factor analysis attempts to investigate underlying factors, and confirmatory factor analysis tests how well the measured variables represent the number of constructs. Exploratory factor analysis was used in this study to determine the factoring situation of the items in the scale and their factor loads.

After conducting the exploratory factor analysis, the researchers performed a confirmatory factor analysis on the scale. The scale's compliance with the factor analysis was assessed with the Kaiser-Meyer-Olkin (KMO) test and the Bartlett test. The KMO value of the 56-item scale was calculated as 0.88, and the Bartlett test was determined to be significant ($\chi 2$ = 7722,135, df = 1540, $p < .05$). The data were determined to be suitable for factor analysis because the KMO coefficient was bigger than 0.60 and because the Bartlett test was significant (Büyüköztürk, 2006).

Varimax analysis was applied to bring together factors with high correlations (Doğan, 2011). Based on the varimax analysis, three factors' eigenvalues were found to be greater than 1. To calculate eigenvalue, a scree plot method was used. A scree plot shows the eigenvalues on the y-axis and the number of factors on the x-axis. Figure 1 shows the maximum number of factors. Additionally, after the sixth factor, the graph shows accelerated decline, meaning that seventh and eight factors' variances were close to each other. This shows that the scale has a six-factor structure (Büyüköztürk, 2006).

As shown in Figure 1, the eigenvalues of the six factors on the scale (21st-Century Skills Knowledge, Pedagogical Knowledge, Mathematical Knowledge, Science Knowledge, Engineering Knowledge, and Technology Knowledge) were 14.928, 4.354, 3.065, 2.315, 2.267, and 2.00,

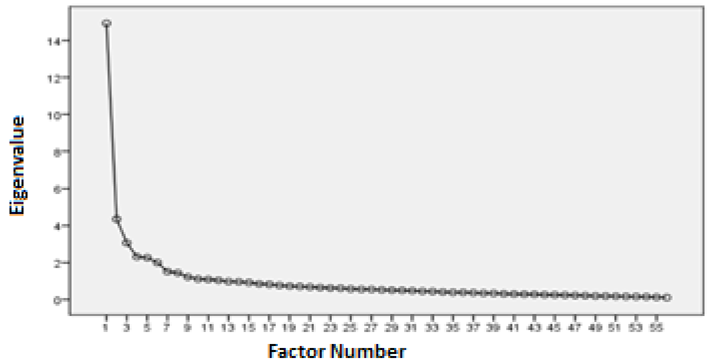

Figure 1. Scatter graph.

respectively. These values were above 1. However, the percentages of variance explained by the factors were 26.657%, 7.774%, 5.774%, 4.133%, 4.049%, and 3.571%, respectively.

Reliability analysis. The STEMPCK Scale's internal consistency coefficient was calculated, and the Cronbach's Alpha values are presented in Table 3. The Cronbach's Alpha value was .95 for the entire STEMPCK Scale, .90 for the 21st-Century Skills Knowledge dimension, .87 for the Pedagogical Knowledge dimension, .85 for the Mathematical Knowledge dimension, .86 for the Science Knowledge dimension, .81 for the Engineering Knowledge dimension, and .78 for the Technology Knowledge dimension.

The variance quantities were ranked as follows: 21st-Century Skills Knowledge was 26.657%, Pedagogical Knowledge was 7.774%, Mathematical Knowledge was 5.774%, Science Knowledge was 4.133%, Engineering Knowledge was 4.049%, and Technology Knowledge was 3.571% (see Table 4). After factor rotation, the number of items for each factor was determined: 21st-Century Skills Knowledge included 15 items with factor loads ranging from 0.423 to 0.760, Pedagogical Knowledge consisted of 12 items with factor loads ranging from 0.434 to 0.724, Mathematical Knowledge consisted of eight items with factor loads ranging from 0.435 to 0.811, Science Knowledge consisted of eight items with factor loads ranging from 0.524 to 0.785, Engineering Knowledge consisted of seven items with factor loads ranging from 0.493 to 0.754, and Technology Knowledge consisted of seven items with factor loads ranging from 0.463 to 0.734. The results indicate that the SPAB's items corrected item-total correlation ranged from 0.306 to

Table 3
Cronbach's Alpha Values for the STEMPCK Scale and Its Components

Dimension	Cronbach's α
STEMPCK Scale	.95
21st-Century Skills Knowledge	.90
Pedagogical Knowledge	.87
Mathematical Knowledge	.85
Science Knowledge	.86
Engineering Knowledge	.81
Technology Knowledge	.78

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0.895. *T*-tests comparing the total scores of the bottom 27% and top 27% for each item indicated that there was an important difference in scores for all items. The scores of the top 27% and bottom 27% of the total group tell us whether an item has discriminated the high scorers and low scorers on the scale.

As shown in Table 5, the correlations between the 21st-Century Skills Knowledge and Pedagogical Knowledge factors (r = .425), the 21st-Century Skills Knowledge and Mathematical Knowledge factors (r = .417), the 21st-Century Skills Knowledge and Science Knowledge factors

Table 4
Results of the Exploratory Factor Analysis of the STEMPCK Scale

Item	*M*	*SD*	Item-total correlation	*t*-value (bottom 27%, top 27%)[a]	Rotator factor load	Common factor load
			21st-Century Skills Knowledge			
CS4	4.42	.714	.511	1.275	.760	.626
CS5	4.26	.726	.534	1.302	.707	.599
CS7	4.40	.794	.489	0.665	.695	.571
CS3	4.34	.718	.536	2.101	.691	.583
CS1	4.30	.718	.574	1.275	.607	.542
CS9	4.45	.915	.384	0.601	.595	.416
CS13	4.26	.718	.595	0.400	.581	.511
CS11	4.16	.856	.438	0.988	.563	.393
CS15	4.42	.795	.449	0.957	.562	.427
CS12	4.09	.791	.535	1.642	.562	.448
CS2	4.21	.700	.563	1.801	.539	.487
CS6	3.99	.843	.558	0.906	.526	.425
CS8	4.14	.814	.540	0.800	.447	.381
CS14	4.07	.857	.402	2.359	.423	.436
			Pedagogical Knowledge			
PK12	4.13	.707	.508	1.311	.724	.584
PK5	3.96	.750	.480	1.127	.689	.541
PK10	4.15	.719	.403	1.847	.674	.488
PK11	3.79	.825	.445	0.400	.633	.476
PK13	4.17	.726	.465	1.839	.629	.501
PK6	4.16	.722	.487	2.532	.613	.472
PK4	4.16	.662	.493	0.406	.601	.452
PK1	4.33	.817	.405	0.781	.559	.400
PK7	4.33	.676	.539	1.948	.543	.534
PK8	4.25	.703	.467	0.994	.528	.451
PK9	4.04	.717	.430	2.052	.518	.361
PK3	3.85	.861	.435	1.371	.434	.312

Mathematical Knowledge						
M2	3.91	.908	.514	1.268	.811	.745
M4	3.49	1.05	.433	0.781	.706	.542
M6	3.74	.957	.440	0.986	.698	.608
M1	3.68	.969	.492	1.602	.698	.575
M9	3.39	.950	.439	0.566	.668	.530
M3	3.15	.858	.341	0.307	.662	.600
M5	3.82	.870	.347	1.766	.495	.307
M10	3.52	1.08	.490	1.426	.405	.405
Science Knowledge						
S5	3.34	.902	.495	2.613	.785	.682
S7	2.85	1.04	.498	0.713	.710	.596
S4	3.50	.916	.502	1.205	.703	.611
S9	3.48	1.21	.369	0.783	.682	.529
S3	3.61	.909	.442	1.171	.673	.563
S1	3.67	.890	.396	1.443	.635	.475
S8	3.55	.960	.451	1.128	.547	.460
S2	3.04	.980	.408	0.863	.524	.417
Engineering Knowledge						
E4	2.95	1.11	.341	2.827	.754	.616
E5	3.34	1.16	.353	1.675	.695	.593
E2	2.68	.964	.346	2.377	.689	.541
E3	2.51	.976	.341	1.977	.682	.575
E7	2.82	.996	.317	2.530	.657	.482
E9	3.90	.990	.372	0.692	.502	.363
E8	4.00	.941	.323	0.818	.493	.327
Technology Knowledge						
T6	3.29	.977	.401	0.430	.734	.625
T1	3.43	.837	.322	0.992	.692	.516
T4	3.66	.933	.410	0.434	.649	.504
T5	3.37	.922	.462	1.130	.616	.497
T9	3.37	.937	.306	1.507	.511	.368
T2	4.02	.741	.450	0.854	.509	.451
T10	4.00	.699	.426	0.484	.463	.331

Note. Factor load values lower than .30 are not shown in this table (Çokluk, Şekercioğlu, & Büyüköztürk, 2014).
[a] The results of the *t*-value comparing the 27% of the students and the top and the 27% at the bottom shows that there is a significant difference in scores from all items (Wiersma & Jurs, 1990).

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(r = .421), the 21st-Century Skills Knowledge and Engineering Knowledge factors (r = .261), and the 21st-Century Skills Knowledge and Technology Knowledge factors (r = .660) were statistically significant ($p < .01$). Moreover, the correlations between the Pedagogical Knowledge and Mathematical Knowledge factors (r = .389), the Pedagogical Knowledge and Science Knowledge factors (r = .361), the Pedagogical Knowledge and Engineering Knowledge factors (r = .508), and the Pedagogical Knowledge and Technology Knowledge factors (r = .427) were significant ($p < .01$). In addition, the correlations between the Mathematical Knowledge and Science Knowledge factors (r = .485), the Mathematical Knowledge and Engineering Knowledge factors (r = .323), and the Mathematical Knowledge and Technology Knowledge factors (r = .474) were significant ($p < .01$). Similarly, the correlations between the Science Knowledge and Engineering Knowledge factors (r = .330, $p < .01$) and the Science Knowledge and Technology Knowledge factors (r = .507) were significant ($p < .01$). In brief, the correlations between the subdimensions of the STEMPCK Scale appeared to be significantly positive. The lowest correlation between the subdimensions of the STEMPCK Scale was 0.261, and the highest correlation was 0.660.

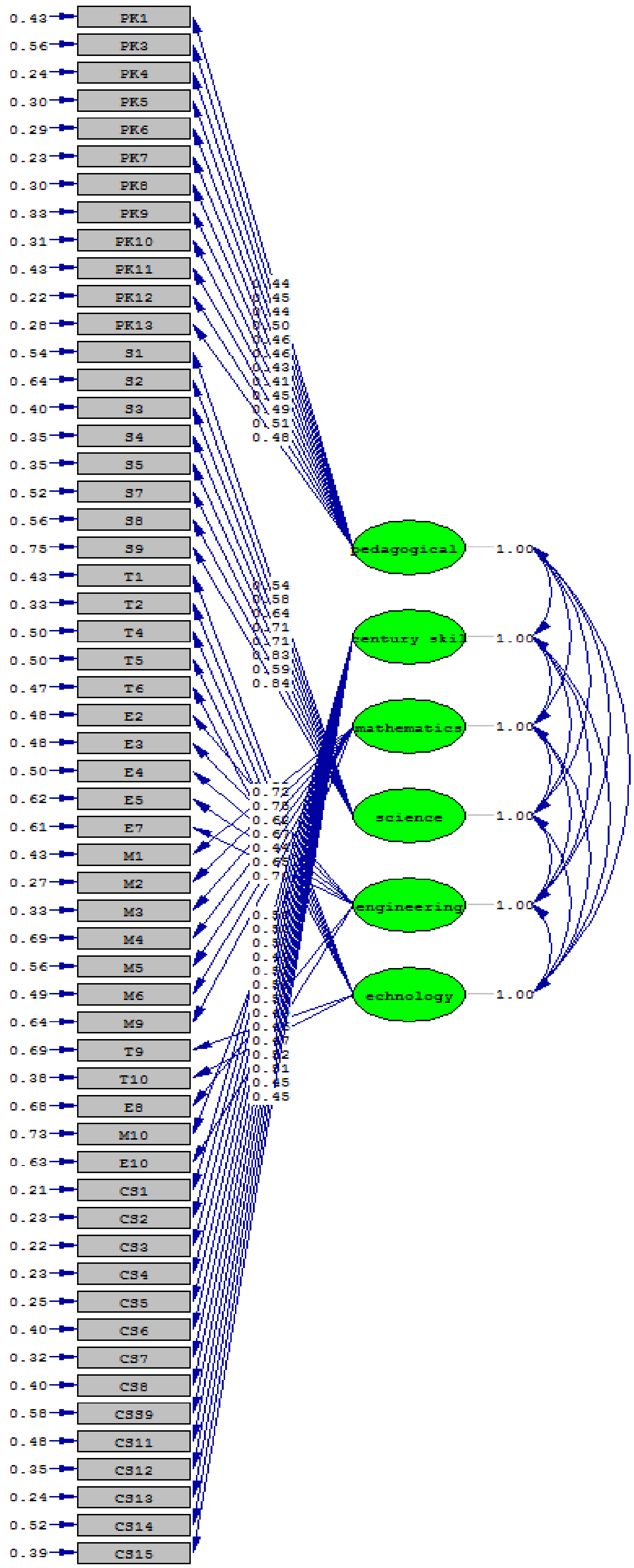
Results of the confirmatory factor analyses. As mentioned previously, exploratory factor analysis of the STEMPCK Scale was conducted with Study Group 1, and confirmatory factor analysis was conducted with Study Group 2. Study Group 2 consisted of 212 preservice teachers in the Mathematics Education, Science Education, Early Childhood Education, and Elementary School Education programs. A confirmatory factor analysis using the structural equation model was conducted to determine the existing structure of the scale (see Figure 2).

Model conformity of the STEMPCK Scale was tested by criteria such as the Goodness of Fit Index (GFI), the Adjusted Goodness of Fit Index (AGFI), the Root Mean Square Error of Approximation (RMSEA), the Comparative Fit Index (CFI), and the Normed Fit Index (NFI; Kılıç & Şen, 2014). Chi-square ($\chi2$), $\chi2/SD$, RMSEA, RMR, GFI, and AGFI are commonly used in confirmatory factor analysis. In large samples, calculated $\chi2$/df ratio can also be used as a criterion

Table 5
Correlation Values for STEMPCK Scale Components' Mean Values and Standard Deviations

Factor	21st-Century Skills Knowledge	Pedagogical Knowledge	Mathematical Knowledge	Science Knowledge	Engineering Knowledge	Technology Knowledge
21st-Century Skills Knowledge	---					
Pedagogical Knowledge	.425**	---				
Mathematical Knowledge	.417**	.389**	---			
Science Knowledge	.421**	.361**	.485**	---		
Engineering Knowledge	.261**	.508**	.323**	.330**	---	
Technology Knowledge	.660**	.427**	.474**	.507**	.280**	---

** $p < .01$.



Chi-Square = 1701.54 *df* = 1469 *p*-value = .00002 RMSEA = 0.034

Figure 2. Confirmatory factor analysis of the STEMPCK Scale.

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Table 6
Fit Indices of STEM Pedagogical Content Knowledge and Acceptable Fit Indices Values

Chi-square value	*p*-value	CFI	NFI	GFI	AGFI	IFI	SRMR	RMSEA
1701.54	$p < .05$	0.93	0.93	0.99	0.97	0.93	0.043	0.034

for conformity adequacy. If calculated $\chi2/df$ ratio is (1) $\chi2 / df < 3$, it can be regarded as good fit; if it is up to (2) $\chi2 / df <5$, it can be regarded as sufficient.

If the GFI and AGFI values are higher than 0.90 (Hooper, Coughlan, & Mullen, 2008; Sümer, 2000) and the RMR and RMSEA values are lower than 0.05 (Jöreskog & Sörbom, 1993; Sümer, 2000), model–data fit is good. However, if the GFI value is higher than 0.85, the AGFI is higher than 0.80, and the RMR and RMSEA values are lower than 0.080, model–data fit is acceptable (Anderson & Gerbing, 1984; Hu & Bentler, 1999; Sümer, 2000). The results of the confirmatory factor analysis for the STEMPCK Scale are shown in Table 6.

According to the confirmatory factor analysis results, conformity between structural equation model and scale was high. Additionally, the Chi-square value was found to be significant. The value of $\chi2$ depends on the size of the sample, and when the size of the sample increases, it provides significant results. Briefly, when the Chi-square value ($\chi2$) is divided by the value of the degrees of freedom (*df*), it shows that the value is less than 3; in other words, based on the results, the model–data fit was high. In addition, if the CFI, NFI, and AGFI values are above 0.90, it indicates that the model–data fit is good. Also, if RMSEA value is 0.034, it indicates that the model–data fit is high. According to confirmatory factor analysis, it was determined that the STEMPCK Scale consists of six subdimensions and that model–data fit was high.

Discussion

The STEM disciplines (science, technology, engineering, and mathematics), Shulman's model of PCK, and theoretical knowledge were used as a basis for the STEMPCK Scale, and items were written based on extensive review of the literature (e.g., Aksu et al., 2014; Bukova-Güzel et al., 2013; Brenneman, 2011; Campbell et al., 2010; Enochs et al., 2000; Faber et al., 2013; Kelleys & Knowles, 2016; Kiray, 2016; Kloosterman & Stage, 1992; Koehler et al., 2011; Önal, 2016; Ryang, 2014; Schmidt et al., 2009; Unfried et al., 2015; Viiri, 2003; Yusof et al., 2012) and interviews. The results of the varimax analyses shaped the factors in the STEMPCK Scale. The STEMPCK Scale consisted of six factors: 21st-Century Skills Knowledge, Pedagogical Knowledge, Mathematical Knowledge, Science Knowledge, Technology Knowledge, and Engineering Knowledge. The total variance of these six factors was 51.958%, and the Cronbach's Alpha value of the scale was 0.95. The Cronbach's Alpha value was calculated as 0.90 for 21st-Century Skills Knowledge, 0.87 for Pedagogical Knowledge, 0.85 for Mathematical Knowledge, 0.86 for Science Knowledge, 0.81 for Engineering Knowledge, and 0.78 for Technology Knowledge. These results show that the developed STEMPCK Scale is reliable.

Additionally, based on the confirmatory factor analysis results, the CFI, GFI, IFI, NFI, and AGFI values were higher than 0.90, indicating that model–data fit was high (Hooper et al., 2008; Sümer, 2000). In addition, the SRMR and RMSEA values (0.043 and 0.034, respectively) were less than 0.05, indicating that model–data fit was high (Anderson & Gerbing, 1984; Hooper et al., 2008; Jöreskog & Sörbom, 1993; Sümer, 2000; Hu & Bentler, 1999). According to the confirmatory factor analysis results, model–data fit was high, and the STEMPCK Scale was found to have six subdimensions. This scale was found to be valid and reliable based on the results of the exploratory and confirmatory factor analyses.

The STEMPCK Scale was developed to assess preservice teachers' STEMPCK. Understanding of teacher candidates' STEMPCK will help teacher educators strengthen their courses and identify gaps in teacher candidates' knowledge that need to be addressed.

Conclusion

The STEMPCK Scale is a valid and reliable instrument that will be used to measure STEMPCK for prospective teachers. A review of the literature found that there were no valid and reliable STEMPCK instruments for preservice and in-service teachers. Therefore, this study will contribute to this side of the STEMPCK literature. The validity and reliability of the instrument was determined using data from 655 students in Science Education, Mathematics Education, Elementary School Education, and Early Childhood Education. However, to use this instrument with different groups, the validity and reliability of the instrument would first need to be tested with those groups.

Some limitations were present in the study. This study was conducted with preservice teachers in the Mathematics Education, Science Education, Early Childhood Education, and Elementary School Education programs in the fall semester of 2017 in a public university in Turkey. Additional research is needed to administer the STEMPCK Scale in different groups or departments (e.g., the chemistry teaching department or the physics teaching department). Furthermore, during the pilot study, interviews were conducted with 40 students from the school of education and 17 students from the school of engineering. Because only one department (the computer science department) actively accepts students,[1] only students from that department were invited to participate in this study, and the researchers conducted interviews with them. Researchers first started the study by reviewing and analyzing the literature about PCK. From various different conceptions given by the scholars, the researchers synthesized their own conception about the constructs to represent the scope of PCK needed by teachers in order to teach STEM subjects in the classrooms. Finally, this is the first study examining this instrument, and additional studies are needed to furnish more evidence of construct validity.

The STEMPCK Scale is a robust instrument that elementary, middle, and high school STEM education program leaders and teacher educators can use to identify what preservice and in-service teachers know in general and what they do not know. Because this instrument is new, researchers are also encouraged to continue testing and refining the scale's content. Finally, this instrument could contribute to studies on teacher professional development and teacher education programs. Gaps in teachers' knowledge that are identified can be used as guidelines for planning more effective professional development programs for teachers.

[1] Due to an insufficient number of faculty members, our university has not completed the conditions required by the Council of Higher Education to accept student to other STEM departments.

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References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1150). Mahwah, NJ: Erlbaum.

Aksu, Z., Metin, M., & Konyalıoğlu, A. C. (2014). Development of the pedagogical content knowledge scale for pre-service teachers: The validity and reliability Study. *Mediterranean Journal of Social Sciences*, *5*(20), 1365–1377. doi:10.5901/mjss.2014.v5n20p1365

Anderson, J. C., & Gerbing, D. W. (1984). The effect of sampling error on convergence, improper solutions, and goodness-of-fit indices for maximum likelihood confirmatory factor analysis. *Psychometrika*, *49*(2), 155–173. doi:10.1007/BF02294170

Appleton, K. (1995). Student teachers' confidence to teach science: Is more science knowledge necessary to improve self-confidence? *International Journal of Science Education*, *17*(3), 357–369. doi:10.1080/0950069950170307

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. *Research in Science Education*, *33*(1), 1–25. doi:10.1023/A:1023666618800

Avery, Z. K. (2009). *Effects of professional development on infusing engineering design into high school science*, *technology*, *engineering and math (STEM) curricula* (Doctoral dissertation). Retrieved from http://digitalcommons.usu.edu/etd/548/

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407. doi:10.1177/0022487108324554

Barnett, J., & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Teacher Education*, 85(4), 426–453. doi:10.1002/sce.1017

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 147–161). Dordrecht, the Netherlands: Kluwer Academic. doi:10.1007/0-306-47217-1_6

Beier, M. E., & Rittmayer, A. D. (2008). *Literature overview: Motivational factors in STEM: Interest and self-concept*. Retrieved from http://www.engr.psu.edu/awe/misc/arps/arp_selfconcept_overview_122208.pdf

Benuzzi, S. (2015). *Preparing future elementary teachers with a STEM-rich*, *clinical*, *co-teaching modeling of student teaching* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3708290)

Binkley M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin P., B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Dordrecht, the Netherlands: Springer. doi:10.1007/978-94-007-2324-5_2

Brenneman, K. (2011). Assessment for preschool science learning and learning environments. Early Childhood Research *and Practice*, *13*(1). Retrieved from http://ecrp.uiuc.edu/v13n1/brenneman.html

Briscoe, C., & Peters, J. (1997). Teacher collaboration across and within schools: Supporting individual change in elementary science teaching. *Science Education*, *81*(1), 51–65. doi:10.1002/(SICI)1098-237X(199701)81:1<51::AID-SCE3>3.0.CO;2-0

Bukova-Güzel, E., Cantürk-Günhan, B., Kula, S., Özgür, Z., & Elçí, A. N. (2013). Scale development for pre-service mathematics teachers' perceptions related to their pedagogical content knowledge. *South African Journal of Education*, *33*(2). doi:10.15700/saje.v33n2a690

Büyüköztürk, Ş. (2006). *Sosyal bilimler için veri analizi el kitabı: İstatistik, araştırma deseni SPSS uygulamaları ve yorum* [Data analysis handbook for social sciences statistics: Research design SPSS practices and interpretation] (6th ed.). Ankara, Turkey: Pegem.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35.

Campbell, T., Abd-Hamid, N. H., & Chapman, H. (2010). Development of instruments to assess teacher and student perceptions of inquiry experiences in science classrooms. *Journal of Science Teacher Education*, *21*(1), 13–30. doi:10.1007/s10972-009-9151-x

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowing: An integrative model for teacher preparation. *Journal of Teacher Education*, *44*(4), 263–272. doi:10.1177/0022487193044004004

Çokluk, Ö., Şekercioğlu, G., & Büyüköztürk, Ş. (2014). *Sosyal bilimler için çok değişkenli istatistik: SPSS ve LISREL uygulamaları* [Multivariate statistics for social sciences: SPSS and LISREL applications] (3rd ed.). Ankara, Turkey: Pegem.

Comrey, A. L., & Lee, H. B. (1992). *A first course in factor analysis* (2nd ed.). Hillsdale, NJ: Erlbaum.

Custer, R. L., & Daugherty, J. L. (2009). Professional development for teachers of engineering: Research and related activities. *The Bridge*, *39*(3), 18–24. Retrieved from https://www.nae.edu/19582/Bridge/16145/16204.aspx

Doğan, T. (2011). Sosyal görünüş kaygısı ölçeği'nin psikometrik özelliklerinin ergenlerden oluşan bir örneklemde incelenmesi [An investigation of the psychometric properties of the social appearance anxiety scale in an adolescent sample]. *Elementary Education Online*, *10*(1), 12–19. Retrieved from http://dergipark.ulakbim.gov.tr/ilkonline/article/view/5000037978/5000036836

Drew, D. E. (2011). *STEM the tide: Reforming science, technology, engineering, and math education in America*. Baltimore, MD: Johns Hopkins University Press.

Eckman, E. W., Williams, M. A., & Silver-Thorn, M. B. (2016). An integrated model for STEM teacher preparation: The value of a teaching cooperative educational experience. *Journal of STEM Teacher Education*, *51*(1), 71–82. Retrieved from http://ir.library.illinoisstate.edu/jste/vol51/iss1/8/

Eilks, I., & Markic, S. (2011). Effects of a long-term participatory action research project on science teachers' professional development. *Eurasia Journal of Mathematics, Science and Technology Education*, *7*(3), 149–160. doi:10.12973/ejmste/75196

Enochs, L. G., Smith, P. L., & Huinker, D. (2000). Establishing factorial validity of the Mathematics Teaching Efficacy Beliefs Instrument. *School Science and Mathematics*, *100*(4), 194–202. doi:10.1111/j.1949-8594.2000.tb17256.x

Epstein, D., & Miller, R. T. (2011). Slow off the mark: Elementary school teachers and the crisis in STEM education. *Education Digest*, *77*(1), 4–10.

Faber, M., Unfried, A., Wiebe, E. N., Corn, J. Townsend, L. W., & Collins, T. L. (2013, June). *Student attitudes toward STEM: The development of upper elementary school and middle/high school student surveys.* Paper presented at the 120th ASSE Annual Conference & Exposition, Atlanta, GA. Retrieved from https://www.asee.org/public/conferences/20/papers/6955/view

Halim, l., Mohd Meerah, T. S., Zakaria, E., Syed Abdullah, S. I. S., & Tambychik, T. (2012). An exploratory factor analysis in developing pedagogical content knowledge scale for teaching science. *Research Journal of Applied Sciences, Engineering and Technology*, *4*(19), 3558–3564. Retrieved from http://maxwellsci.com/print/rjaset/v4-3558-3564.pdf

https://ir.library.illinoisstate.edu/jste/vol53/iss2/2
DOI: https://doi.org/10.30707/JSTE53.2Yildirim

Harris, J. B., & Hofer, M. J. (2011). Technological pedagogical content knowledge (TPACK) in action: A descriptive study of secondary teachers' curriculum-based, technology-related instructional planning. *Journal of Research on Technology in Education*, *43*(3), 211–229. doi:10.1080/15391523.2011.10782570

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal*, *42*(2), 371–406. doi:10.3102/00028312042002371

Hooper, D., Coughlan, J., & Mullen, M. R. (2008). Structural equation modeling: Guidelines for determining model fit. *Journal of Business Research Methods*, *6*(1), 53–60. Retrieved from http://www.ejbrm.com/issue/download.html?idArticle=183

Hu, L.-T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. doi:10.1080/10705519909540118

Hudson, P., English, L. D., Dawes, L., King, D., & Baker, S. (2015). Exploring links between pedagogical knowledge practices and student outcomes in STEM education for primary schools. *Australian Journal of Teacher Education*, *40*(6), 134–151. doi:10.14221/ajte.2015v40n6.8

Hume, A., & Berry, A. (2011). Constructing CoRes—A strategy for building PCK in pre-service science teacher education. *Research in Science Education*, *41*(3), 341–355. doi:10.1007/s11165-010-9168-3

Jöreskog, K. G., & Sörbom, D. (1993). *LISREL 8: Structural equation modeling with the simplis command language*. Lincolnwood, IL: Scientific Software International.

Kelleys, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*, Article 11. doi:10.1186/s40594-016-0046-z

Kennedy, M. M., Ahn, S., & Choi, J. (2008). The value added by teacher education. In M. Cochran-Smith, S. Feiman-Nemser, & J. McIntyre (with K. E. Demers) (Eds.), *Handbook of research on teacher education: Enduring issues in changing contexts* (3rd ed., pp. 1249–1273). New York, NY: Routledge.

Kılıç, H. E., & Şen, A. İ. (2014). UF/EMI eleştirel düşünme eğilimi ölçeğinin Türkçeye uyarlama çalışması [Turkish adaptation study of UF/EMI Critical Thinking Disposition Instrument]. *Eğitim ve Bilim* [Education and Science], *39*(176), 1–12. doi:10.15390/EB.2014.3632

Kiray, S. A. (2016). Development of a TPACK self-efficacy scale for preservice science teachers. *International Journal of Research in Education and Science*, *2*(2), 527–541. doi:10.21890/ijres.64750

Kline, P. (1994). *An easy guide to factor analysis*. London, England: Routledge.

Kloosterman, P., & Stage, F. K. (1992). Measuring beliefs about mathematical problem solving. *School Science and Mathematics*, *92*(3), 109–115. doi:10.1111/j.1949-8594.1992.tb12154.x

Koehler, M. J., Mishra, P., Bouck, E. C., DeSchryver, M., Kereluik, K., Shin, T. S., & Wolf, L. G. (2011). Deep-play: Developing TPACK for 21st century teachers. *International Journal of Learning Technology*, *6*(2), 146–163. doi:10.1504/IJLT.2011.042646

Lee, C. A., & Houseal, A. (2003). Self-efficacy, standards, and benchmarks as factors in teaching elementary school science. *Journal of Elementary Science Education*, *15*(1), 37–55. doi:10.1007/BF03174743

Lee, K.-T., & Nason, R. (2012). Reforming the preparation of future STEM teachers. In S. Yu (Ed.), *2nd International STEM in Education Conference* (pp. 33–39). Beijing, China: Beijing Normal University. Retrieved from http://stem2012.bnu.edu.cn/data/long%20paper/stem2012_19.pdf

Lichtenberger, E., & George-Jackson, C. (2013). Predicting high school students' interest in majoring in a STEM field: Insight into high school students' postsecondary plans. *Journal of Career and Technical Education*, *28*(1), 19–38. doi:10.21061/jcte.v28i1.571

LISREL (Version 8) [Computer software]. Skokie, IL: Scientific Software International.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2nd ed.). Rotterdam, the Netherlands: Sense. doi:10.1007/978-94-6091-821-6

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education*, *31*(2), 289–307. doi:10.1023/A:1013124409567

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.). *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Dordrecht, the Netherlands: Kluwer Academic. doi:10.1007/0-306-47217-1_4

Meng, C. C., Idris, N., Eu, L. K., & Daud, M. F. (2013). Secondary school assessment practices in science, technology, engineering and mathematics (STEM) related subjects. *Journal of Mathematics Education*, 6(2), 58–69. Retrieved from http://educationforatoz.com/images/5_Dec_2013.pdf

Minner, D., & Martinez, A. (2013, April). *A review of STEM research instruments for assessing teacher practices*, *pedagogical content knowledge*, *and content knowledge*. Paper presented at the annual international conference of the National Association for Research in Science Teaching, Río Grande, Puerto Rico.

Minner, D., Martinez, A., & Freeman, B. (2013). *Compendium of research instruments for STEM education. Part 1: Teacher practices*, *PCK*, *and content knowledge.* Waltham, MA: Community for Advancing Discovery Research in Education. Retrieved from https://cadrek12.org/resources/compendium-research-instruments-stem-education-part-i-teacher-practices-pck-and-content-kn

Nadelson, L. S., Seifert, A., Moll, A. J., & Coats, B. (2012). i-STEM summer institute: An integrated approach to teacher professional development in STEM. *Journal of STEM Education*, *13*(2), 69–83. Retrieved from http://ojs.jstem.org/index.php?journal=JSTEM&page=article&op=view&path%5B%5D=1644

National Research Council. (2000). *Educating teachers of science*, *mathematics*, *and technology: New practices for the new millennium.* Washington, DC: National Academy Press. doi:10.17226/9832

National Research Council. (2011). *A framework for K-12 science education: Practices*, *crosscutting concepts*, *and core ideas.* Washington, DC: National Academies Press. doi:10.17226/13165

Önal, N. (2016). Development, validity and reliability of TPACK scale with pre-service mathematics teachers. *International Online Journal of Educational Sciences*, *8*(2), 93–107. doi:10.15345/iojes.2016.02.009

Ostler, E. (2012). 21st century STEM education: A tactical model for long-range success. *International Journal of Applied Science and Technology*, *2*(1), 28–33. Retrieved from http://www.ijastnet.com/journals/Vol_2_No_1_January_2012/3.pdf

Pang, J., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics*, *100*(2), 73–82. doi:10.1111/j.1949-8594.2000.tb17239.x

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K–12 education in science*, *technology*, *engineering*, *and math (STEM) for America's future*. Washington, DC: Author. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

https://ir.library.illinoisstate.edu/jste/vol53/iss2/2
DOI: https://doi.org/10.30707/JSTE53.2Yildirim

Rogers, R. R. H., Winship, J., & Sun, Y. (2016). Systematic support for STEM pre-service teachers: An authentic and sustainable four-pillar professional development model. In K. Dikilitaş (Ed.), *Innovative professional development methods and strategies for STEM education* (pp. 73–90). Hershey, PA: Information Science Reference. doi:10.4018/978-1-4666-9471-2.ch005

Ryang, D. (2014). Development and validation of the Mathematics Teaching Efficacy Scale: Confirmatory factor analysis. *The Mathematical Education*, *53*(2), 185–200. doi:10.7468/mathedu.2014.53.2.185

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123–149. doi:10.1080/15391523.2009.10782544

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. doi:10.3102/0013189X015002004

SPSS Statistics (Version 17) [Computer software]. Chicago, IL: SPSS.

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics*, *109*(3), 153–161. doi:10.1111/j.1949-8594.2009.tb17951.x

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34. doi:10.5703/1288284314653

Sümer, N. (2000). Yapısal eşitlik modelleri: Temel kavramlar ve örnek uygulamalar [Structural equation models: Basic concepts and sample applications]. *Türk Psikoloji Yazıları* [Turkish Psychological Articles], *3*(6), 49–74. Retrieved from https://www.researchgate.net/publication/281981476_Yapidotlesssal_esitlik_modelleri_Temel_kavramlar_ve_ornek_uygulamalar

Tavşancıl, E. (2002). *Tutumların ölçülmesi ve spss ile veri analizi* [Attitude measurement and data analysis with SPSS]. Ankara, Turkey: Nobel.

Unfried, A., Faber, M., Stanhope, D. S., & Wiebe, E. (2015). The development and validation of a measure of student attitudes toward science, technology, engineering, and math (S-STEM). *Journal of Psychoeducational Assessment*, *33*(7), 622–639. doi:10.1177/0734282915571160

van der Valk, A. E., & Broekman, H. G. B. (1999). The lesson preparation method: A way of investigating pre-service teachers' pedagogical content knowledge. *European Journal of Teach Education*, *22*(1), 11–22. doi:10.1080/0261976990220102

Viiri, J. (2003). Engineering teachers' pedagogical content knowledge. *European Journal of Engineering Education*, *28*(3), 353–359. doi:10.1080/0304379031000098265

Voogt, J., & Roblin, N. P. (2010). *21st century skills* (Discussion paper). Retrieved from http://opite.pbworks.com/w/file/fetch/61995295/White%20Paper%2021stCS_Final_ENG_def2.pdf

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), 1–13. doi:10.5703/1288284314636

Wiersma, W., & Jurs, S. G. (1990). Educational measurement and testing (2nd ed.). Boston, MA: Allyn & Bacon.

Wilson, S. (2011, April). *Effective STEM teacher preparation*, *induction*, *and professional development*. Paper presented at the National Research Council Workshop on Highly Successful STEM Schools or Programs for K-12 STEM Education, Washington, DC. Retrieved from http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072640.pdf

Yıldırım, B. (2016). An analyses and meta-synthesis of research on STEM education. *Journal of Education and Practice*, *7*(34), 23–33. Retrieved from http://www.iiste.org/Journals/index.php/JEP/article/view/34597/35577

Yıldırım, B. & Selvi, M. (2015). Adaptation of STEM attitude scale to Turkish. *Turkish Studies: International Periodical for the Languages*, *Literature and History of Turkish or Turkic*, *10*(3), 1117–1130. doi:10.7827/TurkishStudies.7974

Yusof, Y. M., Zakaria, E., & Maat, S. M. (2012). Teachers' general pedagogical content knowledge (PCK) and content knowledge of algebra. *The Social Sciences*, *7*(5), 668–672. doi:10.3923/sscience.2012.668.672

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