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Validation of the Scientific Reasoning Competencies Instrument: Relationships with Epistemological Beliefs and Analytical Thinking

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Abstract
Scientific reasoning competencies (SRC) are an area of competence emphasized in science education and are considered essential in the world of 21st Century skills. Developing these competencies is important for all levels of education, from primary school to university. However, to accurately measure them, measurement tools with validity and reliable evidence are needed. The current study was conducted with two different sample groups. In Study-1 (n = 155), the SRC test consisting of 21 items was adapted into Turkish, and evidence of its validity and reliability was presented. To this end, the Turkish adaptation of the SRC test, which was previously developed and tested for validity in different languages, was conducted in a sample of primary school teacher candidates. In Study-2 (n = 483), the relationship between SRC and epistemological beliefs and analytic thinking skills was examined. Regression analysis showed that epistemological beliefs and analytic thinking were significant predictors of SRC. The study and discussion offer implications for future research on the relationship between SRC and other thinking skills not examined in this research.

Keywords Analytic thinking · Epistemological beliefs · Primary school teacher · Scientific reasoning competencies

Introduction

Creating an experiment, testing a hypothesis, or drawing conclusions from tabulated data are the basic scientific methods and concepts required for inquiry learning (Opitz et al., 2017). These scientific methods and concepts are necessary for

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both professional practice and for solving problems in everyday life (Engelmann et al., 2016). Civic engagement in science and science learning depend upon an accurate understanding of these concepts (Krell et al., 2020a), which are representations of scientific reasoning competencies (SRC) (Krüger et al., 2020). SRC is a complex structure that includes knowing scientific knowledge, knowing how knowledge exists, and knowing why knowledge exists (Krell et al., 2020b). This complexity is indispensable for today's knowledge-based society (Engelmann et al., 2016).

According to Osborne (2013), SRC are one of the most basic skills of the 21st century. Therefore, this study aimed to adapt into Turkish the SRC test (SRC-T), which was previously developed and tested in a German sample (Krüger et al., 2020) and then adapted into English in an Australian sample (Krell et al., 2020b). These competencies have been highlighted in reports written countries (Ministry of National Education [MoNE], 2018; NGSS Lead States, 2013; Victorian Curriculum and Assessment Authority [VCAA], 2016). Furthermore, these competencies are expected to be possessed not only by teachers but also by teacher candidates (Krell et al., 2020b). However, the lack of tools to determine the SRC levels of teacher candidates is a major problem (Osborne, 2013). Turkey does not yet have reliable information regarding the SRC of teachers or teacher candidates. The instrument was evaluated in terms its validity and reliability throughout the course of this research.

Previous literature has reported that SRC depends on advanced cognitive skills (Gjoneska, 2021). Existing knowledge is filtered through inductive and deductive filters before being incorporated into the person's knowledge system. The learned knowledge is then transferred to new situations or hypotheses (Krell et al., 2023). This process illuminates the relationship between analytical thinking skills and SRC (Jastrzębski & Chuderski, 2022). In other words, it is believed that those with analytical thinking will be able to make more robust scientific inquiries (Swami et al., 2014). We decided to examine the relationship between SRC and analytical thinking based on this assertion.

In addition to the structure of SRC being related to cognitive skills, according to Krell et al. (2023), SRC are also a part of teacher candidates' professional competencies. This suggests that teacher candidates be equipped with the necessary competencies to professionally reflect upon teaching-learning processes (Carlson & Daehler, 2019). Teacher candidates' beliefs in this process are also important (Krüger et al., 2020) because, according to Khan and Krell (2019), teacher candidates' epistemological beliefs affect their beliefs about learning and teaching. Therefore, epistemological beliefs can be an effective variable influencing SRC. In fact, according to Osborne et al. (2018), SRC and epistemic beliefs are intertwined. We, therefore, decided to address the relationship between these two in the study, which was structured around two main research questions:

1. Is the Turkish version of the SRC-T appropriate for content validity, construct validity, and internal consistency reliability?
2. What is the relationship between SRC-T, analytical thinking, and epistemological beliefs?

Theoretical Background

Scientific Reasoning Competencies

In science literature, SRC are defined as the process of solving a bounded scientific problem using a set of scientific skills and knowledge (Krell et al., 2023). The skill of solving a scientific problem mentioned here is associated with meta-level thinking (Khan & Krell, 2019). Accordingly, during problem-solving, the individual employs a series of processes such as coding, organizing, and retrieving information, testing, and evaluating (Morris et al., 2012). This is why the claim has been made that the SRC of an individual is related to epistemic knowledge, which includes notions of where and how knowledge is accessed (Kind & Osborne, 2017). It is also believed that SRC are intertwined with reasoning since the individual must first have knowledge about the problem that needs to be solved (Opitz et al., 2017). Science literature has associated this type of scientific reasoning with investigating and modeling experimental processes (Krell et al., 2020b). Utilizing the skills and scientific models necessary for conducting a scientific investigation is the foundation for SRC.

The National Research Council (NRC, 2012) described SRC as "part of the scientific method". In essence, SCR are related to a set of competencies that also fall within the scope of scientific literacy (Opitz et al., 2017). Although these competencies are addressed in different ways throughout various sources, it is broadly understood that they cover basic components such as developing hypotheses, conducting experiments, collecting and interpreting data, developing models and testing these models (Pedaste et al., 2015). What is essential is the content of the component addressed within the scope of SRC and how it is measured. The focus of this research will be on one of these developed tests (Turkish version).

Scientific Reasoning Competencies Test

According to Kind and Osborne (2017), there are different styles of SRC in terms of ontological, epistemic, and procedural aspects. Science education literature has generally only focused on one or two styles. For example, Heijnes et al. (2017) included only modeling from SRC, while van der Graaf et al. (2016) focused on both experimentation and evidence evaluation. Because of this, there is a lack of clarity on SRC in the literature (Opitz et al., 2017). At the same time, two established skills have been identified in the SRC literature. According to Krell et al. (2020b), these are experimental evaluation and modeling. In this context, they developed the SRC-T, which measures these two basic skills. SRC-T is a multiple-choice test and covers the sub-skills of using scientific models, deciding the purpose of models, testing models, and evaluating models.

The original instrument is in German and was later translated into English. To obtain empirical evidence supporting the validity of the instrument's test score interpretation in previous studies, the English version of the instrument was pre-tested quantitatively and qualitatively in the target population (Krell et al., 2020b). In the

quantitative phase, SRC-T was applied to science teacher candidates to ensure test equivalence. The findings were subjected to differential item functioning analysis. In the qualitative phase, one-on-one interviews were conducted with the science teacher candidates. Accordingly, science teacher candidates were asked to work on the instrument and verbalize their thoughts directly. The data obtained from the science teacher candidates were subjected to content analysis. Then, qualitative and quantitative data were combined to understand the validity of the English version of the scale. In the Spanish version of the scale, SRC-T was statistically evaluated using item response theory models (Krell et al., 2020a). The features affecting item quality, differential item functioning, dimensionality, and instrument difficulty were addressed in this context. The findings provided evidence for validity as in the original construct of the instrument.

The SRC-T has a total of 21 items and offers four responses. One of the responses is correct and the others are distractors (for more information, see Krell et al., 2020b). It has been reported that both AERA et al. (2014) standards and Kane's (2013) framework were used in assessing the validity and reliability of the instrument. Three questions were prepared to identify each sub-competency. A sample question is presented in Fig. 1.

Epistemological Beliefs

Individual perspectives on what knowledge are, how it is obtained, and what its limits and criteria might be constitute epistemological beliefs (Perry, 1968). Similarly,

Soy Bean

Portions of Africa are well-known for their extreme climate conditions with very dry and hot weather. A new soy bean species has been bred as part of a research project by the Welthungerhilfe (German Agro Action). In order to find out whether or not this new species can be grown in African Ethiopia, an agricultural research institute has been asked to investigate the crop yield of the new soy bean species.

Which scientific question might underlie this investigation?
Tick one of the boxes below.

- ☐ Under which climatic conditions does the new soy bean species in Ethiopia produce a sufficient crop yield?
- ☐ Is the crop yield of the new soy bean species in the climactic conditions of Ethiopia higher than that of other soy bean species?
- ☐ Can the new soy bean species in Ethiopia be cultivated significantly better than other soy bean species?
- ☐ Does the new soy bean species provide similar crop yields in Ethiopia as it does under laboratory conditions?

Fig. 1 An example of formulating questions in SRC-T

Conley et al. (2004) discussed these beliefs in the dimensions of source, certainty, development, and justification, and mentioned that epistemological beliefs develop over time. The development of individuals' epistemological beliefs is realized through stronger analytical thinking skills and questioning (Alkış Küçükaydın et al., 2023b; Kite et al., 2021). For this reason, epistemological beliefs have become a fundamental topic of research from the past and on into the present day (Conley et al., 2004). This is because epistemological beliefs include individuals' understanding of the nature of knowledge and knowledge about the process of acquiring scientific knowledge (Lederman, 2007), which is all related to learning.

By putting their epistemological beliefs to work, individuals can find opportunities that develop metacognitive behaviors such as problem solving, decision making, and reasoning by searching the nature of knowledge about issues in daily life (Greene et al., 2016; Schommer-Aikins & Hutter, 2002). Today's educational approaches, particularly in the realm of science, set epistemic goals, including how knowledge exists and how scientific knowledge is constructed (Aleixandre & Crujeiras, 2017). To understand the nature of science, both scientific inquiry and experimental applications are fundamental (Schwartz et al., 2007). This is why student participation in scientific research and the development of scientific inquiry skills through science learning has become a primary goal of science education (NRC, 2012).

Scientific reasoning is a form of reasoning in which students develop hypotheses and test them. In this reasoning process, the phenomenon under examination is organized in association with the individuals' prior knowledge, which must happen before new information is sought (Zulkipli et al., 2020). To meet the needs of the 21st Century society, content should be included in the analysis, synthesis, and evaluation stages, which include students' higher-order thinking skills. For students to understand the nature of scientific arguments well, they need to participate in scientific discussions and have a certain level of proficiency with scientific content. For these understandings to be realized in the individual, knowledge about scientific processes and epistemic structures is necessary (Osborne, 2013). Therefore, can the relationship between them contribute to an effective SRC process?

Analytic Thinking

In the complex modern world, people process information they come across in daily life with scientific reasoning and scientific thinking processes. SRC allows people to question whether the information they encounter is true or not (Pennycook et al., 2015). All of this means that individuals using scientific reasoning skills can make logical decisions without having unfounded beliefs and avoiding invalid inferences (Čavojová et al., 2020). Possessing beliefs that are not addressed from a scientific perspective and are, therefore, epistemically suspect (conspiracy, pseudoscientific, and paranormal) can have negative consequences (Alkış Küçükaydın, 2020; Alkış Küçükaydın & Gökbulut, 2020; Alkış Küçükaydın et al., 2023a). To prevent this, it is necessary to reduce susceptibility to cognitive biases and prioritize scientific reasoning and analytical thinking processes (Šrol, 2022). The related literature also

states that there is a negative relationship between analytical thinking and skeptical epistemic beliefs and that analytical thinking reduces the effect of these beliefs (Georgiou et al., 2021; Swami et al., 2014).

Pennycook et al. (2015) stated that analytical thinking is possible by fully understanding what a problem is and sorting that problem into sections. Accordingly, analytical thinking includes skills such as analyzing, evaluating, judging or comparing (Sternberg, 2021). These skills can be handled with scientific reasoning (Pennycook et al., 2015). This is because scientific thinking processes dominate problem-solving; information is analyzed and evaluated, and solutions are produced by dividing them into small units (Robbins, 2011).

With reasoning, the fundamental element of analytical thinking, individuals use alternative stimuli to conclude problems. Sequential and systematic behavior models organize this reasoning. In other words, it contributes to defining and solving the problem to solve an uncertain situation. It creates an idea about what and how the individual should solve it (Robbins, 2011). Individuals with an analytical thinking style solve problems by evaluating them quantitatively and analytically, making them manageable by breaking them down into parts (Jastrzębski & Chuderski, 2022). Analytical thinking forms the basis of individuals' higher-order thinking skills. Therefore, a person with analytical thinking is assumed to be able to use scientific reasoning effectively (Swami et al., 2014). It seems true that analytical thinking supported by SRC will increase the validity of the scientific perspective.

Present Study

Previous studies on SRC have addressed it mainly in the context of primary or secondary school education (Opitz et al., 2017), although a few studies have examined it in a higher education setting as well (Georgiou et al., 2023; Heijnes et al., 2017). However, these studies either addressed reasoning skills in a specific discipline (Cloonan & Hutchinson, 2011) or tried to obtain a generalized reasoning score (Lawson et al., 2000; Tobin & Capie, 1982). It bears mentioning that these instruments have been criticized for not providing psychometrically satisfactory results (Krell et al., 2020b). It is our aim, therefore, to adapt an instrument for determining the SRC of primary school teacher candidates into Turkish.

The SRC-T was originally developed using a German sample, and was then later adapted into English for an Australian sample. To ensure the content validity of the test developed in the German sample, 21 academicians, teachers and researchers were consulted. In monitoring the response processes that constitute the valid evidence of the items that make up the test, the marked retrospective reporting method (attention maps, sequence charts) was used to investigate cognitive processes during eye tracking. During the test's improvement, 644 teacher candidates participated in the study. The values reported regarding the reliability of the test are as follows: Expected-A-Posteriori/Plausible Value (EAP/PV) reliability is 0.81; Cronbachs α per test booklet: 0.44-0.81 (Krüger et al., 2020).

In Turkey, competencies related to SRC are specified by MoNE (2018). In addition, teacher candidates are expected to exhibit these competencies (Higher Education Council, 2018), which include designing experiments for their students, interpreting and testing findings, performing experimental procedures, and testing and evaluating models. Suffice it to say, SRC are a vital component of teacher candidates' professional learning in Turkey. Thus, the first objective of our study was to adapt the SRC-T.

In the second part of the study, we investigated the relationship between SRC and epistemological beliefs and analytic thinking using the SRC-T. Although the previous literature had not directly investigated the relationship between SRC and epistemological beliefs, beliefs about the nature of knowledge and knowing have been shown among cognitive activities and to be associated with scientific reasoning (Yang et al., 2013). It has been reported that the dimensions of epistemological beliefs predict learning approaches that enable understanding a scientific text (Tsai et al., 2011; Yang, 2016). Similarly, scientific reasoning used in solving ill-structured daily life problems has been connected to individuals' epistemological beliefs (Zeidler & Sadler, 2008). There is also preliminary evidence from many educational and psychological studies that epistemological beliefs may be an influential factor in the individual's development of SRC (Mason & Scirica, 2006; Yang et al., 2013). Zeineddin and Abd-El-Khalick (2010) reported that the stronger an individual's epistemological beliefs, the greater the increase of their reasoning abilities. Finally, Yang et al. (2019), who conducted a study with university students from Indian and Taiwanese samples, found significant relationships between epistemological beliefs and SRC levels of Indian students. Their studies measured scientific reasoning with open-ended questions, and performance was evaluated. Accordingly, nonparametric tests were applied to find the interactions between scientific reasoning performance and epistemic beliefs about science. According to the results, there was no relationship between epistemic beliefs and refutation performance for Taiwanese students. In contrast, there was a significant relationship between epistemic beliefs about identifying evidence and development and scientific reasoning skills. Based on this, we decided to test whether epistemological beliefs are a significant predictor of SRC at the level of higher education. Therefore, this situation is addressed in Study-2.

Another variable that has garnered attention in the SRC literature are analytical thinking skills. The literature has mostly focused on conspiracy theories and presented evidence that conspiracy beliefs develop in an environment where analytical thinking is not developed and scientific reasoning is not practiced (Georgiou et al., 2021). Analytical thinking is explained as individuals' preference for thinking about problems rather than emotions when making decisions (Douglas et al., 2017). Accordingly, individuals will engage in a complex thought system when making decisions (Chan et al., 2011), and this requires having advanced epistemological awareness (Jones & Merritt, 1999). Analytical thinking may also be related to epistemological beliefs. However, evidence that addresses this linear relationship has not yet been presented. So, we also tested the relationship between analytical thinking, epistemological beliefs, and SRC in this study. The research was designed and categorized as Study-1 and Study-2.

Study 1: Adaptation of the Scientific Reasoning Competencies Test

Participants

Primary school teacher candidates studying at one of the universities in the Central Anatolia Region of Turkey were included in the study. In this context, data were collected from a university in the Central Anatolia Region of Turkey at the beginning of the 2023-2024 academic year. All of the teacher candidates are studying in the undergraduate program of primary school teaching. A total of 112 (72.3%) female and 43 (27.7%) male teacher candidates between the ages of 17-25 (M = 20.11, SD = 1.51) participated in the study. Of the teacher candidates who participated in the study, 38 (24.51%) were in the first year, 37 (23.87%) were in the second year, 36 (23.22%) were in the third year and 44 (28.38%) in the fourth year. Teacher candidates participate in basic science education from their first year of undergraduate studies and are introduced to the basic principles necessary for scientific inquiry in this process.

Instruments

The Demographic Characteristics Form

The form was prepared by the researchers to obtain information on the teacher candidates, specifically regarding age and gender. SRC-T was added to the continuation of the questions.

Scientific Reasoning Competencies Test Development

The Turkish adaptation of the SRC-T as developed by Krell et al. (2020a) was presented to the candidates. There are 21 multiple-choice tests in the test. Four options are presented for each question. The candidates were given 60 minutes to complete the test. The test was applied face-to-face by the researchers as a paper-and-pencil test.

Procedure

Permissions were obtained for the use of SRC-T before starting the study. Afterward, to follow ethical protocols, permissions were also obtained from the university where the second author of the study was located (Ethic Commission Ref. No: 578980). At this point, the adaptation of the study was able to begin. The translation, review, adjudication, pretesting, and documentation procedure of Harkness et al. (2004) was followed in the adaptation process. The SRC-T was first translated into Turkish by two independent translators, who were science educators fluent in both Turkish and English. They had also both completed their doctoral studies in

English. The translators did not consider the SRC-T in the context of individual words but, as a whole, by the Turkish meaning structure. However, for hypotheses and question sentences, they provided direct translations that aimed to be faithful to the originals. All questions were then reviewed one-by-one in a mini-panel with the authors of this study.

In the next step, the SCR-T was translated back into English by two other translators. One of these translators was a PhD candidate in English Language and Literature and the other was an associate professor in science. The back-translation of the test was again checked by the authors of the study.

The Turkish version of the SRC-T was then sent to two doctoral faculty members in the field of Turkish education. After the checks and corrections regarding the Turkish language structure, a pilot study was conducted with ten teacher candidates outside the study sample regarding comprehensibility. The finalized Turkish version of the SCR-T was then subjected to validity and reliability analyses.

Data Analysis

Both classical test theory and item response theory were utilized in the validity and reliability analysis of SRC-T. Within the scope of classical test theory, KR-20, KR-21, and Cronbach's alpha coefficients were examined in item analysis. Thus, the discrimination (rjx) and item difficulty levels (pjx) of the items in the test were identified. A value between 0-1 is given to pjx, and the closer to 1 that value is, the more difficult the item. On the other hand, rjx takes a value between -1 and +1; a value of 0.30 and above means that the item discrimination is good (Tekin, 1991). KR-20, KR-21, and Cronbach's alpha values are expected to be 0.60 or higher (Hinton et al., 2004). The Test Analysis Program (TAP.exe) was used for item analysis.

In the Krell et al. (2020b) study, SRC-T was evaluated in the Rach model, and the instrument was observed to have a one-dimensional structure. The instrument was also analyzed using the Rach model, and its one-dimensional structure was evaluated in this study. For SRC-T, infit and outfit statistics were used to examine the suitability of an item to the Rasch model within the scope of item response theory (Bond & Fox, 2007). The terms "infit" and "outfit" are statistical concepts used to analyze the measurement process in multiple-choice tests. Infit refers to the agreement or disagreement of an item with the test scale, while outfit measures the disagreement of an item with other items. These values are often used in measurement theory models, particularly the Rasch model, to assess the accuracy of the concept being measured and the quality of the measurement. In Rasch analysis, a "measure" is a numerical value that represents a measured characteristic. This value is calculated using the measurement model and is usually expressed in logit units. In this way, comparisons between different people or objects can be made, and the accuracy of the measurement can be assessed (Lamprianou, 2019).

Infit and outfit values were determined prior to taking measurements on the unidimensional structure of the test used for the study with the results in Table 1. In addition, the Wright Map graphic image was reported for the study (Fig. 2).

Results

Item analyses were first performed according to the classical test theory, and the skewness and kurtosis coefficient of the data varied between +1.04 and -1.05. Accordingly, since the data is in the ±2 range, it is accepted to have a normal distribution (Tabachnick & Fidell, 2007). The Turkish version of SRC-T has a 21-item structure. The minimum score obtained from the test was 1 and the maximum score was 21. The average score of SRC-T was 15. The pjx value for the overall test was .84 and the rjx value was .48. This confirmed that the questions in the test had high discrimination and were difficult. The reliability coefficients of SRC-T were as follows: KR-20=0.79, KR-21 = 0.75, and Cronbach's alpha = 0.83. This means that the reliability of the instrument is high (Hinton et al., 2004).

The item statistics (Table 1) and Wright Map (Fig. 2) values were then analyzed for the same test. According to Table 1, the infit and outfit values of the SRC-T items ranged between 0.6 and 1.4 (Linacre, 2012), confirming the original structure of the instrument. It was noted that the items of SRC-T are adequately represented in the tested Rasch model.

Table 1 Item Statistics

	Proportion	Measure	Infit	Outfit
Q1	0.400	0.4168	1.040	1.047
Q2	0.290	0.9193	0.996	0.989
Q3	0.303	0.8558	1.006	1.006
Q4	0.600	-0.4197	0.995	0.991
Q5	0.381	0.5007	1.015	1.015
Q6	0.200	1.4236	0.988	0.971
Q7	0.574	-0.3099	0.998	1.000
Q8	0.884	-2.0813	1.002	1.002
Q9	0.484	0.0652	1.025	1.027
Q10	0.884	-2.0813	1.021	1.068
Q11	0.355	0.6150	0.981	0.973
Q12	0.252	1.1206	1.010	1.015
Q13	0.529	-0.1214	1.001	1.002
Q14	0.213	1.3432	0.994	0.992
Q15	0.574	-0.3099	0.975	0.972
Q16	0.329	0.7331	0.987	0.978
Q17	0.387	0.4726	0.986	0.980
Q18	0.161	1.6912	0.986	0.976
Q19	0.819	-1.5549	0.982	0.950
Q20	0.471	0.1186	0.995	0.994
Q21	0.374	0.5289	0.978	0.974

Note. *Infit* information-weighted mean square statistic, *Outfit* outlier-sensitive means square statistic

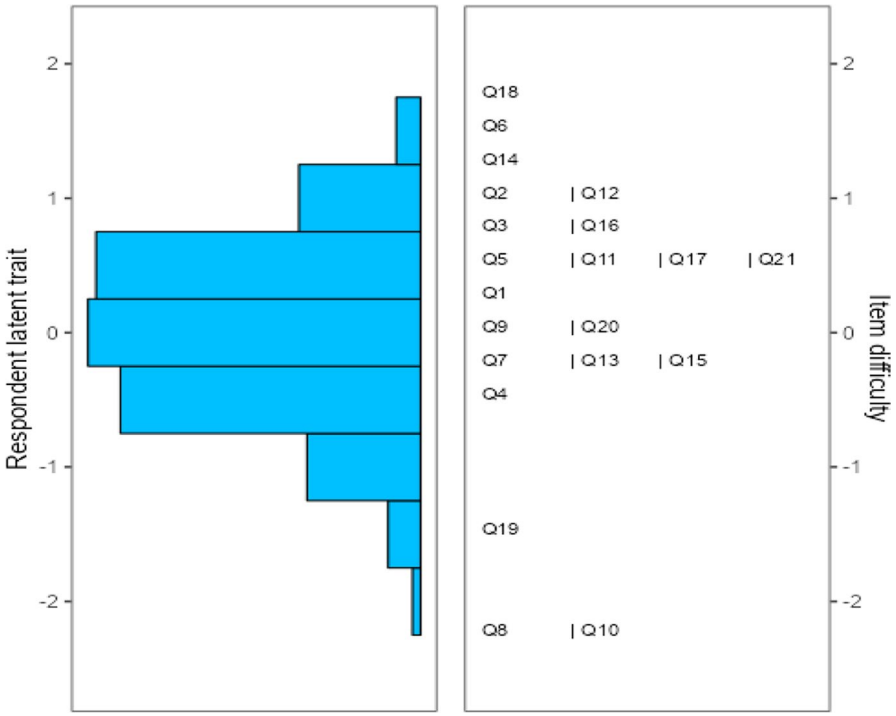

Fig. 2 Wright Map

The 15 questions concentrated in the center of the map in Fig. 2 represent the items that generally pose a medium level of difficulty in the test. These questions have an average level of difficulty. The groups of three questions at the top and bottom of the map represent more difficult and easier items respectively (see the Wrigh Map for the difficulty of the items). This suggests that individuals are exposed to questions of varying difficulty based on their level of ability. Items 14 (Judging the purpose of models), 6 (Generating hypotheses), and 18 (Testing models) appear to be challenging, while items 8 (Planning investigations), 10 (Analyzing data and drawing conclusions), and 19 (Changing models) seem much easier. The general difficulty level of the test and the average ability level of the individuals may suggest that the test is a balanced measurement tool. This means that individuals with different ability levels were able to validly complete the test.

Discussion

Understanding SRC is important to ensure that science education at all levels develops sufficiently enough to meet 21st Century needs (Osborne, 2013). In addition, knowing the SRCs of teachers and teacher candidates can help in monitoring their growth and improving their education (Mathesius et al., 2016).

Various validity and reliability evidence has been presented for the German and English versions of the test. In the present study, the test was analyzed according to both classical and item response theory. Test analyses showed that the results were consistent with previous versions although items were found to be more difficult in the English version of the SRC-T than in the German version (Krell et al., 2020b). In this study, the overall difficulty level of the test was found to be high. In addition, both the English and Turkish versions appeared challenging for the items that included asking for suggestions for the model and testing the model. In the English version, the items related to planning the research were reported to be quite easy, while in the Turkish version, the questions related to planning the research, analyzing the data, and modifying the models were found to be among the easier ones. Despite this discrepancy, the instrument is largely equivalent to the original. The SRC-T exhibited a unidimensional model in the German, English, and Turkish versions (Krell et al., 2020a, b). This serves as a strong indicator of test equivalence (Ercikan et al., 2010).

In addition, the test validity of the English version was examined in a sample consisting of secondary, primary, and preschool teacher candidates, but this study on the Turkish adaption was conducted only with primary school teacher candidates. The varying levels of item difficulty compared to other versions may be related to this. Science teacher candidates may have also had the opportunity to spend more time on science due to their curriculum. This may have led to higher test scores (Mathesius et al., 2016).

Finally, examining the teacher training curricula of these three countries and analyzing which competencies are emphasized could shed light on how to improve scientific reasoning across the board.

Study-2: Investigating the Relationship between Scientific Reasoning Competencies, Analytical Thinking and Epistemological Beliefs

Participants

The participants of this study were primary school teacher candidates studying in three universities in the Central and Southeastern Anatolia regions of Turkey. The participants ranged between the ages of 17 and 33 ($M = 21.37$, $SD = 2.52$), and consisted of 350 (72.5%) female and 133 (27.5%) male candidates.

Instruments

The Demographic Characteristics Form

The demographic characteristics form was developed by the researchers to obtain age and gender information from the candidates. The items belonging to SRC-T,

epistemological beliefs scale and analytical thinking scale were added to continue the form.

Scientific Reasoning Competencies Test- Turkish Version

SRC-T adapted into Turkish within the scope of Study-1 was used for this test. There are 21 items in the test. Within the scope of this study, Cronbach's alpha coefficient of SRC-T is 0.72.

Epistemological Beliefs Scale

This scale developed by Conley et al. (2004) was used in the study and scale consists of source (5 items), certainty (6 items), development (6 items), and justification (9 items) dimensions. In the 5-point Likert-type scale (1=strongly disagree; 5=strongly agree), items in the source and certainty dimensions are reversed. This total score obtained from the scale reflects complex epistemological beliefs. Özkan (2008) adapted and used the scale in Turkish before. Confirmatory factor analysis was first applied upon considering the validity and reliability studies of the scale. The fit index values of the scale were calculated as follows: x^2/df=4.96, RMSEA = 0.08 [90% CI; 0.07 /0.10], AGFI = 0.95, NFI = 0.95, GFI = 0.95, CFI = 0.96, TLI = 0.96. Cronbach's alpha coefficient of the scale is 0.82.

Analytical Thinking Scale

The 42-item the Rational-Experiential Inventory (Epstein et al., 1996) was used to assess the participants' analytical thinking skills. In the scale, analytical thinking styles (12 items) and experiential thinking styles (30 items) were evaluated. The 42 items in the scale were examined, but only those that included the analytical aspect were used. A 5-point Likert-type scale (1=strongly disagree; 5=strongly agree) mean score is calculated. Items 2, 5, 6, 7, and 8 of the scale are reverse coded. A higher score on the scale is interpreted as a higher level of analytical thinking skills. The validity and reliability of the scale were conducted within the scope of this study with Cronbach's alpha coefficient of the scale is 0.90, AVE value is 0.79, and CR value is 0.94. The goodness of fit values are as follows: x^2/df= 4.92, RMSEA = 0.07 [90% CI;0.08/0.10], AGFI = 0.90, NFI = 0.90, GFI = 0.94, CFI = 0.91, TLI = 0.90. Goodness-of-fit measures are used to determine how well the tested model fits the theoretical model and assess the validity and reliability of the model. In this context, the scale shows a good fit (Bentler, 1990).

Data Analysis

In the analysis of the data, normality distributions were first tested and then descriptive statistical analyses were performed. The data were found to be within ±2 (0.16

and -0.32 for SRC-T, 0.55 and 1.94 for epistemological beliefs, 0.32 and -0.01 for analytical thinking) and had a normal distribution (Tabachnick & Fidell, 2007).

Regression analysis was used to analyze the data. Prerequisite assumptions for regression analysis were tested. Kurtosis critical ratio value (<10) was examined (Kline, 2015) with this in mind. Variance Inflation Factor (VIF) (between 1.00 and 1.02) and tolerance coefficients (between 0.98 and 0.99) values were investigated in regression analysis. SRC-T scores were then converted into standard Z-scores.

Results

Descriptive Statistics

Table 2 presents the descriptive analysis of the scores obtained from the three instruments. Candidates' scores on SRC-T were generally low (M = 8.35, SD = 2.46). However, epistemological beliefs (M/k = 3.37, SD = 8.70) and analytical thinking skills (M = 3.37, SD = 6.01) were in midpoint. Each sub-dimension of epistemological beliefs was found to be in midpoint (M/k_{source}=3.28, SD = 2.76; $M/k_{certainty}$=3.37, SD = 3.23; $M/k_{development}$=3.32, SD = 3.27; $M/k_{justification}$=3.46, SD = 4.36).

Regression Analysis

Epistemological beliefs and analytical thinking skills were tested via regression analysis to determine whether they were significant predictors of SRC (Table 3). When the binary and partial correlations between epistemological beliefs, analytical thinking, and SRC were examined, it was seen that there was a moderate and positive relationship between epistemological beliefs and SRC (r = 0.42, p < 0.05).

Then, when analytical thinking was controlled, it was found that the relationship between SRC and epistemological beliefs was at a lower level (r = 0.07, p < 0.05). A moderate and positive relationship (r = 0.34, p < 0.05) was discovered between analytical thinking and SRC. However, it was determined that this relationship level decreased when epistemological beliefs were controlled (r = 0.20, p < 0.05).

Table 2 Descriptive Statistics

Instruments	Number of items (k)	Range	Mean	Mean/k	SD
SRC-T	21	1-0	8.35	-	2.46
Epistemological beliefs	26	1-5	87.81	3.37	8.70
Source	5	1-5	16.43	3.28	2.76
Certainty	6	1-5	20.23	3.37	3.23
Development	6	1-5	19.96	3.32	3.27
Justification	9	1-5	31.17	3.46	4.36
Analytic thinking	12	1-5	40.49	3.37	6.01

Table 3 Regression Analysis

Variable	B	β	t	p	Binary r	Partial r
Constant	9.182	-	6.66	0.00	-	-
Epistemological beliefs	0.30	0.011	0.23	0.00	0.42	0.07
Analytic thinking	0.14	0.034	0.74	0.01	0.34	0.20
$R = 0.72$, $R^2 = 0.51$, $F(2,480) = 0.30$, $p = 0.00$						

Epistemological beliefs and analytical thinking variables together have a high and significant relationship with teacher candidates' SRC ($R = 0.72$, $R^2 = 0.51$, $p < 0.05$). Moreover, epistemological beliefs and analytical thinking together explain approximately 51% of the total variance in SRC. According to the standardized regression coefficient, the relative importance of the predictor variables is epistemological beliefs and analytical thinking.

When the t-test results regarding the significance of the regression coefficients were examined, it was seen that both analytical thinking and epistemological beliefs were significant predictive variables on SRC. According to the regression analysis results, the regression equation for predicting SRC is as follows:

$$SRC = 9.182 + 0.30\ epistemological\ beliefs + 0.14\ analythic\ thinking$$

In order to present more comprehensive results, the predictive properties of the sub-dimensions of epistemological beliefs on SRC were also tested. Accordingly, regression analysis was repeated for each sub-dimension. Accordingly, whether the sub-dimensions of epistemological beliefs, source, certainty, development, justification and analytical thinking skills together are significant predictors of SRC was tested by regression analysis. When the pairwise and partial correlations between the sub-dimensions of epistemological beliefs, analytical thinking and SRC were examined, a low level and negative correlation was found between the source sub-dimension and SRC (r = -0.25, $p<0.05$), a moderate level and negative correlation between the certainty sub-dimension and SRC (r = -0.42, $p < 0.05$), a moderate level and positive correlation between the development sub-dimension and SRC ($r = 0.30$, $p < 0.05$), and a moderate level and positive correlation between the justification sub-dimension and SRC ($r = .32$, $p < .05$). When analytical thinking was controlled, the relationship between SRC and the sub-dimensions of epistemological beliefs was found to be low (r_{source}=-0.22, $p<0.05$; $r_{certainty}$=-0.22, $p < 0.05$; $r_{development}$=0.30, $p < 0.05$; $r_{justification}$=0.20, $p < 0.05$). According to the results, it is seen that the sub-dimensions of epistemological beliefs are individually predictors of SRC.

Discussion

Previous literature has pointed out some possible relationships between SRC, epistemological beliefs, and analytical thinking (Chan et al., 2011; Jastrzębski & Chuderski, 2022). Epistemological beliefs and analytical thinking were shown as variables that

could be meaningful predictors of SRC (Krell et al., 2023). We tested this relationship between these three variables in the study and found that epistemological beliefs and analytical thinking did appear to be significant predictors of SRC.

SRC being compatible with epistemological beliefs is theoretically compatible because epistemological beliefs, which include beliefs about knowledge and the nature of science, are related to cognitive activities that include reasoning (Conley et al., 2004). Yang et al. (2013) reported that epistemological beliefs are an effective variable in understanding reading texts that require scientific reasoning. However, epistemological beliefs have a nature that is affected by the culture and educational experiences of every individual (Özkan, 2008). That being the case, individuals' epistemological beliefs develop in different ways. Yang (2016) evaluated 106 studies on epistemological beliefs and noticed that cultural differences shape beliefs, and are therefore an important factor in SRC. The relationship between SRC and epistemological beliefs, which was previously discussed in Europe and a few Asian countries (Taiwan and India), was also confirmed in the current study. Therefore, cultural experiences contribute to the development processes of epistemological beliefs in different ways, which enables SRC to develop uniquely for every individual. In short, although the development and process of epistemological belief and SRC are different, there is a relationship between these two variables. However, we did also detect a relationship between SRC and analytical thinking in this research.

There was no evidence of a relationship between SRC and analytical thinking in the previous literature, although the literature indicates that belief in conspiracy theories affects analytical thinking, which, in turn, has the potential to affect SRC (Gjoneska, 2021; Swami et al., 2014). Interventions meant to stimulate scientifically-based reasoning do appear to help improve performance (Georgiou et al., 2023). Applying the basic principles of scientific research certainly occurs more easily if realistic information is presented, and this then facilitates scientific reasoning. Training programs that support analytical thinking can directly contribute to the development of SRC. Therefore, addressing the close relationship between epistemological beliefs, analytical thinking, and SRC with this pioneering study may offer insights that can be useful in future development of this field.

Limitations and Implications for Study-1 and Study-2

Although SRC-T was introduced into the Turkish literature, this study had some limitations. First, SRC-T focuses only on the experimental evaluation and hypothetical modeling sub-competencies of scientific reasoning. As it only addresses two of the six competencies mentioned in the previous literature (Kind & Osborne, 2017), the focus would be considered relatively narrow. However, due to the nature of multiple-choice tests (Shavelson, 2013), this limitation should be met as normal. Paper-and-pencil applications in multiple-choice tests may address some skills related to the research process and ignore others. In addition, SRC-T mainly focuses on two sub-competencies and focuses on the components of generating research questions, developing formulas, generating hypotheses,

planning research, analyzing data, developing models, testing, and evaluation, which include these competencies. Therefore, it is possible to say that it is quite suitable for application in its current state.

Another limitation of the study was that only 155 primary school teacher candidates were included in the sample for Study-1. Since the focus of the study is test adaptation, the sample size should be reasonably small. In future studies, SRCs of teacher candidates can be examined on larger samples by considering additional evidence. Longitudinal studies can be useful in such assessments. Convergent and discriminant validity evidence of the test can also be considered.

SRC studies have been found in German and Austrian samples in previous literature (Khan & Krell, 2019; Kind & Osborne, 2017; Krell et al., 2023). Again, regarding SRC, Yang et al. (2019) have conducted studies with Taiwanese and Indian samples. This study provides information about SRC in the Turkish sample. We find it valuable that all of these studies provide preliminary information regarding SRC in different language and cultural contexts for future researchers. However, while previous literature only provided evidence about SRC, this study presented information about the relationships between SRC, epistemological beliefs, and analytical thinking. Future contributions on the relationships between SRC and other thinking skills could help expand and improve the literature.

Finally, the current study showed that epistemological beliefs and analytical thinking are significant predictors of SRC. It would be beneficial to focus on the development of epistemological beliefs, which include the belief in what knowledge, is and how it is formed, in teacher training programs. Certainly, examining the effects of developmental interventions that include analytical thinking skills on SRC may be insightful in supporting SRC.

Conclusion

In this study, the Turkish adaptation of the SRC-T, for which German and English evidence was previously presented, was conducted, and it was found that the SRC-T is reliable and valid in the Turkish context. Evidence was then presented that supported epistemological beliefs and analytical thinking being significant predictors of SRC. Consequently, this study had a pioneering quality. It also provided information regarding variables that should be considered in the development of SRC for teacher candidates. For this reason, more information could be obtained about the predictive variables of SRC by examining the current study in different cultures. Based on the findings of the current study, the development and change in SRC can be monitored through intervention studies focusing on the development of epistemological beliefs and analytical thinking skills.

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Data Availability The datasets created during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval The study was in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Dicle University Scientific Ethics Evaluation Committee (Ref: 578980) obtained ethical committee approval.

Informed Consent Informed consent was obtained from all individual.

Conflict of Interest The authors declare that they have no conflict of interest.

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