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Development of a metaconceptual awareness and regulation scale

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ABSTRACT

This study aimed to develop the Metaconceptual Awareness and Regulation Scale (MARS) – a self-report instrument for measuring the extent to which students realise, monitor, and evaluate their ideas. MARS consists of 10 items scored on a six-point Likert scale for two factors: metaconceptual awareness and metaconceptual regulation. A pilot study was conducted with 349 10th grade students while 338 11th grade students participated in the validation study. In order to test the two-factor structure of MARS, confirmatory factor analysis was employed with data from the validation study. Findings supported the two-factor structure of the MARS instrument. For further validity evidence, the relationship between students' metaconceptual awareness and regulation and their use of learning strategies were examined using canonical correlation analysis. A significant correlation was found between the factors of MARS and learning strategies. Research and practical applications of MARS by science education researchers and teachers are discussed.

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Metacognition; metaconceptual awareness; metaconceptual regulation; scale development; factor analysis; canonical correlation analysis

Introduction

A universal goal of science teaching is to improve students' understandings of science concepts. This goal requires students to engage in deep examination of their own ideas as they listen to and evaluate the ideas of others and embodies a constructivist theory of learning as students build and change their understandings of science concepts. Therefore, among many different possible positions on learning (e.g. behavioural, cognitive, developmental perspective, etc.), we take a constructivist stance on learning in the present study. According to this perspective, learning is a process in which students must be actively involved in and recognise their responsibility for learning. Through this active process, learners use their existing ideas to make sense of new situations or data; in other words, they link between their ideas and new ideas to make interpretations, draw conclusions, and, in turn, construct meaning while they are interacting with the environment (von Glasersfeld, 1993). Learning, therefore, can be viewed as a conceptual change process where an individual's knowledge structure develops and changes over time (Driver & Oldham, 1986). In

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order for these changes to occur, it is of paramount importance that learners should first be aware of their ideas and the limitations in those ideas. Unless they know the limitations in their current knowledge, they cannot critically think about the implications of new ideas. In addition, they should learn to monitor and control their learning (Posner, Strike, Hewson, & Gertzog, 1982). In this sense, Gunstone (1992) claims that students have some perceptions about their learning processes, the purposes of learning, and their development as a result of a learning activity; and they make decisions during the learning activity. As Gunstone (1992) stated, all of these emphasise the role that metacognitive processes play in learning such as awareness and control:

> By metacognition I mean the amalgam of student knowledge, awareness and control relevant to their learning. I have argued an important complementarity between metacognition and constructivism: knowledge, awareness and control are personal constructions, an appropriately metacognitive learner is one who can effectively undertake the constructivist process of recognition, evaluation and, where needed, reconstruction of existing ideas. (Gunstone, 1992, p. 135)

Increasingly, research on learning science concepts has focused on the metacognitive skills a student can bring to bear on his or her learning (Scott, Asoko, & Leach, 2007). Learners who employ metacognitive skills are able to reflect on their own learning and on the ideas of others. Metacognitive thinking can take a variety of forms but it allows students to realise what, how, and why they are learning a specific task, the cognitive strategies that could be used to learn a topic, how ideas of others impact their own ideas, and how they can connect instruction to assessment. As a result, learners capable of applying metacognitive skills to deal with different situations and different contexts are more effective learners (Georghiades, 2004b).

At this point, we should digress to briefly address some differences among metacognitive processes, metacognitive skills, and metacognitive thinking. Metacognitive processes are described as internal executive processes that supervise and control cognitive processes in the course of a learning task (Gourgey, 2001) whereas metacognitive skills refer to procedural knowledge involving intentional control over one's learning. Planning, monitoring, and evaluating are examples of some metacognitive skills (Brown, 1978; Kluwe, 1987). Lastly, metacognitive thinking is a reflective abstraction on thinking and learning with the intent of engaging in self-appraisal and self-management of learning (Fisher, 1998). Although researchers agree that metacognition is fundamental to deep learning, definitions of metacognition are wide-ranging and subject to debate (Brown, 1987; Hacker, 1998), and researchers have proposed different categorisations for the various components of metacognition (Brown, 1987; Chi, 1987; Flavell, 1979). Among these various categorisations, we adopted Brown's (1987) framework of metacognition for this study as described later.

In a meta-review of research on metacognition, Wang, Haertel, and Walberg (1990) concluded that metacognition was one of the best predictors of learning. Literature also emphasised the relationship between students' use of learning strategies and metacognition (e.g. Capa Aydin, Uzuntiryaki, & Demirdogen, 2011; Lee, Lim, & Grabowski, 2010; Pintrich, 2002; Schraw, 2001; Sperling, Howard, Staley, & DuBois, 2004; Vrugt & Oort, 2008). For example, Sperling et al. (2004) reported that there was a significant and positive correlation between students' use of learning strategies and metacognitive awareness.

Learning strategies include rehearsal, elaboration, organisation, and metacognitive self-regulation. While students engage in surface learning by memorising the task in rehearsal, they employ deep learning processes in elaboration and organisation by connecting new information with existing structure and arranging the task to better understand it, respectively. Metacognitive self-regulation is also deep learning strategy since students plan, follow, and evaluate their learning process (Entwistle, 1988; Garcia & Pintrich, 1994; Pintrich, 2004).

Given the role that metacognition plays in learning, researchers have studied this construct in disciplines such as science (e.g. Anderson & Nashon, 2007; Wang, 2015), mathematics (e.g. Efklides & Vlachopoulos, 2012; Hart & Memnun, 2015), reading (e.g. Jou, 2015; Norris & Phillips, 2012), and problem solving (e.g. Cornoldi, Carretti, Drusi, & Tencati, 2015; Mayer, 1998). With respect to research in science education, many researchers consider metacognition to be central to the process of change from every day to scientifically accepted ideas (Chi, Slotta, & de Leeuw, 1994; Pintrich, Marx, & Boyle, 1993; Posner et al., 1982).

Engaging in the process of changing a conception, students need to compare the reasons underlying their existing knowledge with reasons underlying the conceptions of other people; evaluate new conception in terms of intelligibility, plausibility, and fruitfulness; and reorganise their cognitive structures accordingly. As a result, one's awareness about his/her ideas, monitoring change in existing structures, and control over evaluating new conceptions require metacognitive processes. Although researchers agree that metacognition plays a crucial role when students' conceptions change, advances in this area of research are limited by lack of an instrument capable of capturing metaconceptual components during actual learning (Yuruk, Beeth, & Andersen, 2009). Taking the conceptual change literature into consideration (e.g. diSessa, 2008; Hewson, Beeth, & Thorley, 1998; Inagaki & Hatano, 2008; Vosniadou, 2003; Vosniadou, Vamvakoussi, & Skopeliti, 2008), researchers view metacognition to be at the heart of conceptual change learning and have proposed a 'metaconceptual' construct. According to Thorley (1990), metaconceptual and metacognitive constructs differ from each other in that metacognitive is related to one's own thinking about thinking whereas metaconceptual means one's reflection on his/her conceptions. While metacognitive activities tend to enhance one's performance in a task, metaconceptual activities have potential to impact one's conceptual structures (Yuruk et al., 2009). Yuruk's studies highlight the role of metaconceptual activities in conceptual understanding and elimination of misconceptions in science (Yuruk et al., 2009; Yuruk, Selvi, & Yakisan, 2011). In particular, interventions in which students were engaged in metaconceptual activities improved students' awareness about their past and current conceptions, enabled them to monitor their existing conceptions as well as the way they changed their conceptions, promoted evaluation of conceptions, and thereby enhanced learning. On the other hand, the field lacks an instrument capable of measuring metaconceptual components. Such an instrument would have potential not only for measuring metaconceptual components but also for helping teachers shape their instruction in light of student answers. Therefore, combining Brown's (1987) framework for metacognition and Thorley's (1990) metaconceptual construct, our study focused on developing the Metaconceptual Awareness and Regulation Scale (MARS), an instrument capable of measuring a student's metaconceptual awareness and regulatory skills comprising monitoring and evaluation when they are learning topics in the context of chemistry.

Our instrument is intended to distinguish between metacognition and Thorley's (1990) 'metaconceptual' definition. The purpose of the present study, then, was to develop MARS as a valid and reliable scale that measures students' metaconceptual awareness and regulatory skills when learning concepts.

Review of related literature

Flavell (1979) introduced the term metacognition to refer to 'knowledge and cognition about cognitive phenomena' (p. 906). The briefest definition for this perspective can be stated as: 'cognition about cognition' (Flavell, 1985, p. 104), 'thoughts about thoughts, knowledge about knowledge, or reflections about actions' (Weinert, 1987, p. 8) or 'thinking about thinking' (McCormick, Dimmitt, & Sullivan, 2012, p. 69). According to Brown (1987), metacognition is an individual's understanding of knowledge generation that can direct their use of that knowledge during learning. Common to each of these definitions is an awareness of and control over cognitive processes. However, in addition to mere awareness, Baird, Fensham, Gunstone, and White (1991) added components for processing, evaluating, and deciding to their definition of metacognition in the following: 'a person's knowledge of the nature of learning, effective learning strategies, and his/her own learning strengths and weaknesses; awareness of the nature and progress of the current learning task (i.e. what you are doing and why you are doing it); and control over learning through informed and purposeful decisions making' (p. 164). Considering the multifaceted nature of metacognition, Hennessey (1999) summarised the common characteristics of metacognition as an 'awareness of one's own thinking'; 'an awareness of the content of one's conceptions'; and 'active monitoring of one's cognitive processes' (p. 3). While cognitive processes promote one's learning, metacognitive processes monitor those processes, including changes in various components of a conception – thus metacognition involves second-order cognitive processes (Flavell, 1976). Learners utilise cognitive processes to complete a task whereas they employ metacognitive processes to understand how they are performing that task (Garner, 1987). Metacognition, therefore, involves reflection on components of a conception, which requires reviewing the learning process, connecting prior knowledge with newly learned material, and identifying mistakes during learning. Essentially, it is the monitoring processes that distinguish metacognition from cognition: cognitive activity may occur without utilising critical thinking (although learning may be limited in that case) but metacognitive activity cannot take place without being critical of your own or others' ideas.

Due to some vagueness in the definitions of metacognition (Brown, 1987), researchers have proposed different categories for metacognition. Flavell (1976) classified metacognition into metacognitive knowledge and metacognitive experiences. Metacognitive knowledge refers to one's knowledge that is related to a cognitive task, actions, or experiences. On the other hand, metacognitive experiences consist of 'conscious affective or cognitive experiences' during an intellectual activity (p. 906). By contrast, Chi (1987) suggested three types of meta-knowledge that are much more complex: meta-declarative knowledge, meta-strategies, and meta-procedural knowledge. While Chi's meta-declarative knowledge is similar to Flavell's metacognitive knowledge, meta-strategies and meta-procedural knowledge are more akin to metacognitive experiences.

In a similar vein, Brown (1987) put forth two categories for metacognition: (1) knowledge of cognition and (2) regulation of cognition – 'each feeding on the other recursively' (Brown, 1987, p. 67). Knowledge of cognition includes declarative, procedural, and conditional knowledge. The key descriptions for declarative knowledge include 'knowing what', for procedural knowledge 'knowing how', and for conditional knowledge 'knowing when and why'. Regulation of cognition then refers to skills such as planning, monitoring, and evaluation. Planning involves selection and use of an appropriate strategy to successfully perform a task such as assigning study time or making predictions about an outcome. Monitoring involves awareness of one's understanding during performance such as self-testing during learning and, lastly, evaluating refers to appraisal of the products and learning process such as evaluating the outcome against a specific criterion. While knowledge of cognition reflects metacognitive awareness, regulation of cognition involves metacognitive judgements and monitoring.

Consequently, having examined various definitions of metacognition, we adopted the framework with two components suggested by Brown (1987) for the present study. We believe this framework is more applicable to academic learning settings as Baker and Brown (1984) stated as well.

On the other hand, although both components in Brown's (1987) framework are necessary for learning they may not lead to change in one's conceptual structures (Yuruk et al., 2009). Students need to be aware of their cognitive structures to revise their ideas and control conceptual change processes (Beeth, 1998b; Vosniadou, 2003; White & Gunstone, 1989). Likewise, conceptual change does not solely imply a change in students' abilities to verbally explain a concept (Lewis & Linn, 1996); instead it includes changes in the way teachers and students interact around learning in order for conceptual change to occur (Beeth, 1998b). Thorley (1990) distinguished between metacognitive and metaconceptual constructs – while metacognitive is used to describe one's reflection about his/her thinking, metaconceptual refers to reflection about the contents of his/her conceptions. To put it differently, metacognition is a more inclusive term that includes metacognitive knowledge and processes acting on one's conceptual system. The prominent goal of science education is therefore to promote understanding at a metaconceptual level (NRC, 2012). Being metaconceptual means being aware of one's ideas, checking one's own and others' ideas, commenting on the reasons underlying an idea, comparing ideas with others, supporting or contradicting those ideas, and deciding possible explanations which is the basis of conceptual change (Hewson et al., 1998; Yuruk, 2005). Classical approaches to describing conceptual change learning viewed these changes as a replacement of theory-like misconceptions with new conceptions (e.g. Hewson & Thorley, 1989; Posner et al., 1982). It acknowledged that being metaconceptual about one's ideas was a necessary condition for conceptual change. Vosniadou's framework theory approach for conceptual change (e.g. Vosniadou, 2003; Vosniadou et al., 2008) pointed out that metaconceptual awareness is a requirement for conceptual change to occur. Vosniadou et al. (2008) endorsed that in order to avoid synthetic models or misconceptions, learners should first be aware of their internal inconsistencies. In the same sense, Inagaki and Hatano (2008) viewed conceptual change as an incongruity-reducing process and emphasised that learners should be aware of, monitor, and judge their ideas, which is being metaconceptual, to achieve conceptual change. Considering misconceptions as faulty extensions of productive knowledge (Smith, diSessa, & Rochelle, 1998), diSessa

(2008) proposed that conceptual change occurred when novices' fragmented knowledge structures became organised like the knowledge structures of experts. He pointed out the importance of metaconceptual awareness and monitoring of one's own fragmented pieces of knowledge in order for conceptual change to be achieved. Overall, metaconceptual awareness and regulation play a paramount role in conceptual change process and understanding science. Despite the consensus among researchers about the essential role of metaconceptual awareness and regulation in changing students' conceptions (diSessa, 2008; Hewson & Thorley, 1989; Inagaki & Hatano, 2008; Posner et al., 1982; Vosniadou, 2003; Vosniadou et al., 2008; White & Gunstone, 1989; Zohar & Barzilai, 2013), the literature contains no explicit mechanism to study the two metaconceptual components we have identified. Therefore, we developed the MARS instrument with the purpose of assessing these two metaconceptual components. Considering the theoretical distinction between metacognitive and metaconceptual, and adopting the framework of metacognition proposed by Brown (1987), we propose two metaconceptual components: metaconceptual awareness and metaconceptual regulation. Metaconceptual awareness refers to one's awareness about her/his understanding of a concept. Metaconceptual regulation includes one's monitoring of comprehension and one's commitments to her/his or others' ideas on a concept.

Measurement of metacognitive and metaconceptual components

Metacognition can be measured and evaluated through on-line or off-line methods (Veenman, 2012). On-line methods, such as observation, thinking aloud, and accuracy ratings, are described as assessment of metacognition while performing a task, that is, during one's actual performance, to capture the thoughts of the learner. For example, Pressley and Afflerbach (1995) examined how students use monitoring skills in reading via think-aloud interviews. However, the data collection and scoring procedure is complex and time-consuming and needs effort. Therefore, using on-line methods may not be practical for large groups of students (Azevedo, Moos, Johnson, & Chauncey, 2010; Jacobse & Harskamp, 2012). Off-line assessment methods refer to assessment before or after a learning task to determine the frequency and quality of strategies used by the learner. Self-report questionnaires and interviews are off-line methods. For example, the Index of Reading Awareness (IRA, Jacobs & Paris, 1987) contains 20 multiple choice questions and mainly assesses metacognition in reading comprehension under four factors related to planning, evaluation, regulation, and conditional knowledge. Another instrument, the Metacognitive Assessment Inventory (MAI, Schraw & Dennison, 1994), is a self-report instrument with 52 items containing two factors: general metacognitive knowledge and regulation of cognition. While the IRA considers metacognition within a specific context, reading, the MAI focuses on metacognition in general learning. Regarding metacognitive monitoring, Leonesio and Nelson (1990) utilised students' self-reports; students retrieved some information presented to them and evaluated their learning. This research relies on the idea that students' ability to make appropriate judgements about their knowledge is an indicator of their metacognitive monitoring. The other self-report instrument, the Motivated Strategies for Learning Questionnaire (MSLQ, Pintrich, Smith, Garcia, & McKeachie, 1991), includes 81 items in the motivation and learning strategies section. The learning strategy section contains 12 items concerning students' use of metacognitive strategies such as planning, monitoring, and regulating. Like the MAI, the MSLQ assesses metacognition for general learning. Although off-line measurement methods are practical for a large group of assessment, they are not adequate to capture metacognitive processes and are subject to a learner's recall of their thinking. Taking the complex and somewhat vague nature of metacognition into consideration, it is suggested by cognitive psychologists that multiple techniques are needed to capture any metacognitive processes (Garner & Alexander, 1989). However, considering the benefits of off-line measurement methods like self-report instruments for large groups of students and especially for teachers who have little time to administer individual assessments, there is need for valid and reliable off-line measurement methods with practical implications for classroom teachers (Jacobse & Harskamp, 2012; Schellings, 2011).

While the instruments described above evaluate aspects of metacognition in different contexts, there is no instrument that measures metacognition for concept learning. Therefore, in the present study, taking Brown's (1987) framework of metacognition and Thorley's (1990) distinction between metacognitive and metaconceptual constructs, we developed MARS to measure students' metaconceptual awareness and regulation using self-report data. We should emphasise that MARS is different from other self-report instruments (e.g. Leonesio & Nelson, 1990; Schraw & Dennison, 1994) since MARS measures metaconceptual components through rigorous statistical techniques. The other self-report instruments lack a clear benchmark of evaluation whether the items are appropriate for measuring metacognition and they have psychometrically sound properties. These instruments focus on the students' thinking about their cognitive skills whereas we focus on students' thinking about the content of their conceptions (e.g. their metaconceptual awareness and regulation). Yuruk (2005) stresses that metaconceptual thinking cannot be thought of apart from content that students are supposed to learn. Thomas and McRobbie (2001) also highlighted that there is a strong need for instruments capable of measuring metacognition in science learning settings. We provided chemistry content to students so that they could think about their own conceptual thinking and learning. Thus, MARS has the potential to more accurately measure metaconceptual components since it particularly focuses on one's awareness and control over conceptual structures.

Methodology

Sample

This study involved two samples of public high school students from the eastern part of Turkey. While a total of 349 10th grade students (158 females, 188 males and 3 non-respondents) from four different high schools participated in the pilot study, there were 338 11th grade students (157 females, 169 males and 12 did not indicate) from five different high schools in the validation study.

Context

Public high schools in Turkey follow the chemistry curriculum of the Turkish Ministry of National Education. Chemistry course is offered two hours a week at the 10th grade level and three hours a week at the 11th grade level. The topics in the 10th grade chemistry curriculum are atomic structure, the periodic table, chemical bonding, states of matter, and mixture whereas the 11th grade curriculum includes chemical reactions and energy, rate of reactions and chemical equilibrium, equilibrium in aqueous solutions, electrochemistry, and nuclear chemistry. Students complete secondary education in four years and then the ones who are successful on the university entrance examination attend a university. Students should have a high score on this examination in order to be admitted to the top universities in Turkey. Consequently, there is a competitive high school environment (Aksit, 2007). In addition, teachers' instruction in secondary science classes is heavily based on directly providing information to students through lecturing – rarely using laboratories – and textbooks are the main resource available to students in their classes (Gencer & Cakiroglu, 2007; Özden, 2007).

Instruments

In this study, to measure students' metaconceptual awareness and regulation in learning concepts in the context of chemistry, the MARS was developed. When first developing the MARS scale, an item pool consisting of 17 items was generated in two factors specifically taking Brown's (1987) and Thorley's (1990) studies into account. These items were examined by three experts from science and mathematics education and one from educational measurement to assure they contained content validity. Based on feedback from these experts, five items were deleted since they focused on 'metacognitive components' instead of 'metaconceptual components'. For instance, two of the items deleted were 'While learning a chemistry topic, I monitor how I learn' and 'I question whether I reached my goals after I study a chemistry topic.' These items emphasised learning process in general instead of one's reflection about his/her conceptual system. Thus, we decided to remove these items from the final version of the MARS instrument. An expert in Turkish then examined the items in terms of language to ensure fidelity of translation. Next, semi-structured interviews were conducted with six 10th grade students (three females and three males) in order to provide answers to the following questions: 'Do the respondents understand the items as we intended? Is the vocabulary appropriate for the respondents? Is the scale in the best language for the respondents? Does the scale format flow well?' Finally, a 12-item MARS was administered to 349 10th grade students for our pilot study.

The other instrument used in this study was the MSLQ developed by Pintrich et al. (1991) and adapted into Turkish by Sungur (2004). This questionnaire aims to measure students' motivational orientations and their use of learning strategies in a course. It consisted of a total of 81 items on a seven-point rating scale ranging from 1 (not at all true of me) to 7 (very true of me). It includes 'motivation' and 'learning strategies' sections. The motivation section contains six sub-factors and 31 items while there are nine sub-factors and 50 items in the learning strategies section. Since it is a modular scale and researchers could use any factor based on their needs, we selected rehearsal (4 items), elaboration (6 items), organisation (4 items), and metacognitive self-regulation (12 items) sub-factors for this study to determine students' learning strategies and to provide further validity evidence. The CFA results for the MSLQ showed that the data fit the model with satisfactory fit indices: Normed Fit Index (NFI) = .88; Non-Normed Fit Index (NNFI) = .90; Comparative Fit Index (CFI) = .91; Root-Mean-Square Error of Approximation (RMSEA) = .08

(90% CI = .08, .09). Table 1 displays sample items and Cronbach's alpha reliabilities for the each sub-factor. In addition, reliabilities for the original scale developed by Pintrich et al. (1991) are also presented.

Procedure

At the beginning of the study, approval for conducting this study was obtained from the Ethics Committee of the Ministry of National Education in Turkey. In addition, students were informed about the study and had their parents sign consent forms. The first author of the study conducted all interviews, which lasted approximately 20 minutes, and administered MARS during attendance hours at each high school. It took approximately 15 minutes for students to complete the MARS instrument in both the pilot and the validation studies.

Data analysis

In this study, first, the factor structure of MARS was examined via exploratory factor analysis for the pilot data. Statistical analyses were performed using SPSS 20.0 for Windows. Then, in order to test the factorial structure of MARS, confirmatory factor analysis (CFA) was conducted using LISREL 9.1 for Windows with SIMPLIS command language via the maximum likelihood estimation method. Lastly, further validity evidence was provided using canonical correlation analysis via SPSS 20.0 for Windows.

Results

Pilot study

The 12-item MARS was piloted with 349 10th grade high school students. In order to investigate the factorial structure of MARS, an exploratory factor analysis with principal components and direct oblimin rotation was performed. The Kaiser–Meyer–Olkin measure of sampling adequacy was found to be .84, which shows that the sampling adequacy is satisfactory to proceed with factor analysis. Bartlett's test of sphericity is significant ($\chi^2(66) = 961.02$, $p < .001$), indicating that the correlation matrix is not an identity matrix and the data approach multivariate normality. In order to determine the number of factors retained, scree test (Cattell, 1966), parallel analysis (Horn, 1965), and the conceptualisation of metaconceptual components were used. Each analysis indicated

Table 1. Sample items and reliability coefficients of the MSLQ sub-factors

Sub-factors	Sample item	Cronbach's alpha for this study	Cronbach's alpha for the original study
Rehearsal	I memorise key words to remind me of important concepts in chemistry.	.65	.69
Elaboration	I try to relate ideas in chemistry to those in other courses whenever possible.	.76	.76
Organisation	I make simple charts, diagrams, or tables to help me organise course material.	.66	.64
Metacognitive self-regulation	When reading for chemistry, I make up questions to help focus my reading.	.76	.79

two factors underlying the data. It was found that the metaconceptual regulation factor explained 33% of the total variance and the metaconceptual awareness factor accounted for 11.9% of the total variance. Overall, the two factors explained 44.9% of the total variance in the MARS scores. Table 2 shows the pattern and structure loadings of the two-factor MARS and mean, standard deviation, skewness, and kurtosis values for each item of the 12-item MARS. All factor pattern coefficients were greater than .30, which was satisfactory according to Stevens (2009). However, although item 6 ('I am aware of my knowledge I gained in my daily life related to chemistry') and item 12 ('I become aware of the importance of a chemistry topic') should have been loaded to the metaconceptual awareness factor, they were loaded to the metaconceptual regulation factor. Therefore, these two items were deleted from further analyses as DeVellis (2003) suggested.

Based on the results of our exploratory factor analysis, the final form for the MARS instrument was obtained (see Appendix 1). It included 10 items in a six-point Likert-type scale from never (1) to always (6) with the two underlying factors of metaconceptual

Table 2. The pattern and structure loadings of the two-factor MARS and mean, standard deviation, skewness, and kurtosis values for each item of the 12-item MARS.

Items	Pattern matrix		Structure matrix		*M*	SD	Skewness	Kurtosis
	Factor 1	Factor 2	Factor 1	Factor 2				
Item 4: I question whether my prior knowledge related to a chemistry topic is plausible.	.77	−.14	.71	.16	3.83	1.44	−.10	−.61
Item 2: While learning a chemistry topic, I monitor the changes in my ideas related to the/that topic.	.70	−.05	.69	.22	3.54	1.39	−.02	−.43
Item 3: I consider if I can use the knowledge I learned recently in the chemistry course in various topics.	.68	−.10	.66	.32	3.39	1.55	−.03	−.71
Item 11: I evaluate whether the ideas coming from my friends, my teacher, or other sources (book, journal, etc.) related to a chemistry topic are plausible or not.	.63	.07	.64	.16	4.00	1.43	−.16	−.61
Item 1: While learning chemistry topics, I compare whether my ideas are consistent with the ideas coming from my friends, teacher, or other sources (book, journal, etc.)	.60	−.02	.60	.21	3.41	1.43	−.00	−.48
Item 8: While learning a chemistry topic, I compare my prior knowledge with the new knowledge.	.54	.14	.59	.34	3.72	1.46	−.05	−.59
Item 6: I am aware of my knowledge I gained in my daily life related to chemistry.	.50	.17	.56	.36	3.48	1.53	−.02	−.67
Item 12: I become aware of the importance of a chemistry topic.	.37	.28	.47	.42	4.02	1.42	−.12	−.61
Item 5: I know what I did *not* understand about a chemistry topic.	−.14	.80	.38	.81	4.66	1.34	−.42	−.70
Item 7: I know what I learned about a chemistry topic.	.08	.78	.32	.76	4.51	1.31	−.30	−.63
Item 10: I become aware that I understood a topic related to chemistry.	.03	.75	.17	.74	4.76	1.33	−.45	−.68
Item 9: I use my prior knowledge related to a chemistry topic.	.31	.40	.47	.52	4.34	1.43	−.26	−.71

Note: Factor 1, metaconceptual regulation factor; Factor 2, metaconceptual awareness factor; *M*, mean; SD, standard deviation.

awareness and metaconceptual regulation. Taking high scores from the factors indicated that students used their metaconceptual awareness and regulation when learning chemistry concepts more than the students who scored low on these factors.

The factors presented below reflected metaconceptual components in our analysis:

> Metaconceptual Awareness (four items): This factor reflects one's awareness about his/her current or already existing conceptions. Sample items in this factor included: 'I know what I did not understand about a chemistry topic' and 'I know what I learned about a chemistry topic.' The internal consistency of the scores was estimated by Cronbach alpha and found as .71 (95% CI = .65, .75), which was satisfactory. (Nunnally & Bernstein, 1994, p. 264)

> Metaconceptual Regulation (six items): This factor is related to generating information about an ongoing cognitive activity and making judgmental decisions about existing ideas or new concepts when one encounters a new concept or idea from other sources such as people, textbook, etc. Sample items in this factor included: 'While learning a chemistry topic, I monitor the changes in my ideas related to the/that topic' and 'I question whether my prior knowledge related to a chemistry topic is plausible.' The Cronbach alpha coefficient was calculated as .75 (95% CI = .70, .78). (Nunnally & Bernstein, 1994, p. 264)

Validation study

In order to test the two-factor structure of MARS, CFA was employed with data obtained from 338 11th grade students. Before performing CFA, univariate and multivariate normality were checked for these factors. We calculated skewness and kurtosis values for each item in MARS (see Table 3) and ensured univariate normality. For multivariate normality, we found multivariate kurtosis to be 1.190. Based on the criterion of Finney and DiStefano (2006) for multivariate kurtosis, therefore, multivariate normality was assured. As a result, we chose the maximum likelihood estimation method. NFI, NNFI, CFI, and The RMSEA were employed for the model data fit assessment. To evaluate model fit, two fit indices named absolute and incremental can be used (Hu & Bentler, 1995). In this study, both fit indices were employed. As an absolute fit index, which evaluates how well the model fit the sample data (Hu & Bentler, 1999), RMSEA with 90%

Table 3. Factor pattern and structure coefficients and measurement errors in the CFA and mean, standard deviation, skewness, and kurtosis values for each item of the 10-item MARS.

Items	Factor 1	Factor 2	Measurement error	*M*	SD	Skewness	Kurtosis
Factor 1							
Item 4	*.70*	.50	.51	4.01	1.54	−.15	−.76
Item 2	*.65*	.47	.57	3.61	1.47	−.02	−.58
Item 3	*.45*	.32	.80	3.30	1.58	.08	−.75
Item 10	*.66*	.48	.57	3.81	1.57	−.08	−.75
Item 1	*.65*	.47	.58	3.52	1.54	−.02	−.64
Item 7	*.71*	.51	.50	3.66	1.46	−.04	−.58
Factor 2							
Item 5	.41	*.57*	.68	4.76	1.28	−.45	−.67
Item 6	.48	*.66*	.56	4.46	1.35	−.27	−.66
Item 9	.48	*.66*	.56	4.76	1.27	−.44	−.68
Item 8	.45	*.63*	.60	4.26	1.42	−.22	−.64

Notes: Pattern coefficients are presented in italics while structure coefficients are presented in nonitalics. Pattern and structure coefficients are equal for the items with their related factors. Since pattern coefficients of related factors are equal to '0', they are not shown in the table. Factor 1, metaconceptual regulation factor; Factor 2, metaconceptual awareness factor; *M*, mean; SD, standard deviation.

confidence interval was examined. CFI, NNFI, and NFI were the incremental fit indexes, which measure the improvement in fit by comparing the target model with the null model (Hu & Bentler, 1999), used in this study. Bentler (1992) proposed that CFI, NFI, and NNFI values greater than .90 indicated a well-fitting model. RMSEA values lower than .05 is representative of good fit (Browne & Cudeck, 1993); however, MacCallum, Browne, and Sugawara (1996) specified cutoff points and noted that RMSEA values between .08 and .10 represented mediocre fit. The results of the CFA showed that there was a good fit to the data (NFI = .96; NNFI = .96; CFI = .97; RMSEA = .07; 90% CI = .05, .08). This demonstrated that MARS did indeed have a two-factor structure consisting of metaconceptual awareness and metaconceptual regulation. It should be noted that the correlation between metaconceptual awareness and metaconceptual regulation was found to be .72. Table 3 depicts the standardised factor pattern coefficients, factor structure coefficients, and measurement errors in the CFA and mean, standard deviation, skewness, and kurtosis values for each item of 10-item MARS.

Cronbach's alpha reliability coefficients for the metaconceptual awareness and metaconceptual regulation factor scores were calculated as .72 (95% CI = .67, .77) and .80 (95% CI = .77, .83), respectively, which were satisfactory (Nunnally & Bernstein, 1994, p. 264). Item-total correlations ranged from .45 to .57 for metaconceptual awareness factor and ranged from .41 to .62 for metaconceptual regulation factor, indicating that all items in each dimension contributed to the scale's reliability.

In order to provide further validity evidence, we investigated the relationship between students' metaconceptual components and learning strategies via canonical correlation analysis. It is one of the multivariate techniques researchers use to investigate how two sets of variables are related to each other. It is a more appropriate technique when a researcher is interested in linear combinations of variables rather than in the relationship between individual variables (Stevens, 2009). In this study, we performed canonical correlation analysis between a set of metaconceptual variables and a set of learning strategies variables. Metaconceptual variables were awareness and regulation, while learning strategies variables were rehearsal, elaboration, organisation, and metacognitive self-regulation. Results yielded two pairs of canonical variates. The first canonical correlation was .62 with 38% overlapping variance and the second was .20 with 4% overlapping variance. With two canonical correlations included, χ^2 (8) = 176.35, $p < .001$ and with the first canonical

Table 4. Canonical correlation analysis results.

	First canonical variate	
Variables	Correlation	Coefficient
Metaconceptual variables		
Awareness	.79	.40
Regulation	.94	.72
Per cent of variance	.76	
Redundancy	.29	
Learning strategies variables		
Rehearsal	.48	−.18
Elaboration	.91	.51
Organisation	.66	.14
Metacognitive self-regulation	.92	.58
Per cent of variance	.58	
Redundancy	.23	
Canonical correlation	.62	

correlation removed, χ^2 (3) = 13.42, $p < .001$. Table 4 presents the canonical correlation and coefficients for the first pair of canonical variate. A cutoff correlation of .30 was used to examine the relationship between the variables and the canonical variates (Tabachnick & Fidell, 2007). The first pair of canonical variates indicated that there was a positive correlation between metaconceptual variables (awareness and regulation) and two of the learning strategies variables, elaboration and metacognitive self-regulation. This means that students who are high in metaconceptual awareness and regulation tend to use deeper learning strategies which are elaboration and metacognitive self-regulation.

Discussion

In this study, we validated the MARS for measuring the extent to which students can realise, monitor, and evaluate their ideas in the context of chemistry. As a result of an extensive review of literature on metacognition, interaction with educators to ensure content validity, our pilot study with 349 10th grade high school students to test the factorial structure of the scale, validation study (main study) with 338 11th grade students to confirm the structure of the scale, and finally further analysis to provide additional evidence for validation, we validated the final form of MARS consisting of 10 items and measuring two factors: metaconceptual awareness and metaconceptual regulation. While the metaconceptual awareness factor aimed to measure whether students refer to their conceptual ecology, the metaconceptual regulation factor assessed whether students make judgemental decisions related to their conceptual structure while learning a concept in chemistry. Here, we should emphasise that MARS has the same limitations like any other self-report instruments and should be used with on-line measurement methods to get real-time data on metaconceptual processes. The MARS instrument fills a gap in the literature with a valid and reliable instrument capable of measuring metaconceptual awareness and regulation.

Although the major focus of science education still remains to deepen students' science learning, there is little evidence that science learning has improved over the decades (Thomas, 2012). Metacognition and its implications for conceptual change hold great promise for deeper and more successful science learning (Baird & Northfield, 1992; Beeth, 1998a; Blank, 2000; Georghiades, 2004a; Yuruk et al., 2009). Experiencing learning as conceptual change, learners should consider what they know related to the concept, compare and contrast different explanations underlying each concepts, engage in argumentation to support or oppose an idea, and make reasoned decisions about any explanation they choose (Hewson, & Beeth, 1993). Consequently, metaconceptual activities like the ones investigated in this study are essential for conceptual change to occur in science. In particular, during learning, students with high metaconceptual tendencies can become aware of and gain control over their conceptual structure when changing their conceptions. The MARS instrument we developed in this study can be used to document students' use of metaconceptual awareness and regulation. When teachers wish to identify the extent to which their students utilise metaconceptual activities, they can use scores from MARS to inform design of their instruction in ways that support students as they engage in conceptual change processes.

In addition, results from our factor analyses and results from our canonical analysis support findings from previous studies (e.g. Capa Aydin et al., 2011; Efklides, 2006;

Kuhn & Pearsall, 1998; Lee et al., 2010; Luwel, Torbey, & Verschaffel, 2003; Pintrich, 2002; Siegler, 1996; Sperling et al., 2004; Vrugt & Oort, 2008). Several researchers have proposed that there was a theoretical relationship between metacognition and strategy use (Dunlosky, 1998; Hacker, 1998; Kuhn & Pearsall, 1998; Siegler, 1996). In line with this theoretical assumption, researchers found significant and positive correlation between metacognition and strategy use (Luwel et al., 2003; Sperling et al., 2004; Vrugt & Oort, 2008). Vrugt and Oort (2008) reported that metacognition was effective when students used deep cognitive strategies, while not effective when they used surface cognitive strategies. Luwel et al. (2003) found a strong relationship between students' metacognitive knowledge and their strategy choice and Sperling et al. (2004) showed that there were strong correlations between metacognition and learning strategies. In the current study, we found a significant relationship between metaconceptual components and learning strategies. In other words, students who are aware of what they know and what they do not know, consistently monitor their learning process, check the consistency of their existing knowledge with the knowledge coming from others, and evaluate the plausibility of knowledge are likely to use deeper learning strategies like elaboration. Instead of simply memorising concepts, such students make connections between their prior ideas and new knowledge, explain concepts in their own words, ask questions, and construct analogies more so than students who do not. Considering the positive relation between metaconceptual components and deep learning strategies found in this study as well as the positive relation between deep learning strategies and understanding reported in literature, we may infer that metaconceptual variables might play a crucial role in student understanding. Future studies should investigate this relationship to provide empirical evidence for our claim. In this regard, MARS will be a beneficial instrument to help researchers and teachers assess specific metaconceptual components.

In this study, we developed MARS to measure whether students realise, monitor, and evaluate their ideas. Although chemistry was the context for developing MARS, we did not question whether the metaconceptual constructs in MARS are domain-general or domain-specific. Our results, therefore, may not generalise to other content areas, and this matter remains open for further investigation. Indeed, there is a debate in literature about whether metacognitive knowledge and skills are domain-general or whether they are domain-specific (Kelemen, Frost, & Weaver, 2000; McCormick et al., 2012; Schraw, 2001; Scott & Berman, 2013). According to Kelemen et al. (2000), metacognition is domain-specific whereas Scott and Berman (2013) and Schraw (2001) reported that metacognitive knowledge and regulation were domain-general. Van der Stel and Veenman (2013) indicated that metacognitive skills evolved within specific domains and then transferred across domains. Some researchers (Pintrich, 2002; Veenman, Van Hout-Wolters, & Afflerbach, 2006) suggest that students have general metacognitive knowledge and skills and they use them when needed in a particular situation. According to McCormick et al. (2012) metacognitive knowledge may be both domain-general and domain-specific; students may need to know how to study in general and when they need to study specifically. Still, whether domain-general or domain-specific, it is accepted that metacognition and metaconceptual features have a crucial role in learning. In a similar vein, metaconceptual activities have an impact on one's conceptual system. Therefore, more research is warranted at the metaconceptual level. MARS, which we developed in the present study, can be employed by both researchers and teachers to assess students' metaconceptual awareness and regulation, which are important for meaningful understanding of concepts.

Another important point worth noting is related to the nature of the instruments that are used to measure metacognition. In the present study, we utilised an off-line, self-report method to assess students' metaconceptual awareness and regulation, assuming that students would provide sincere answers. However, MARS could also be used along with online methods (e.g. observation) to increase its reliability and to obtain real-time data on students' metaconceptual processes. In addition, although MARS is a valid and reliable scale for measuring the extent to which students realise, monitor, and evaluate their ideas, it does not mean that this scale could be used to explore all aspects of students' metaconceptual tendencies.

Implications for science education

The MARS instrument can be used by teachers to assess students' metaconceptual awareness and regulation. Teachers can utilise MARS to get a general idea about their students' metaconceptual levels during or shortly after concept learning. Using the results, teachers could design instruction to explicitly stimulate students' metaconceptual awareness and/or regulation in future units of instruction. In these kinds of instructions, teachers play a critical role in offering students ample activities that could address reflection on the thinking process (Yuruk et al., 2009). For instance, they may encourage their students to realise the purposes of tasks, to think about what they are doing in the activities and why, to follow their conceptions during activities, and to evaluate their conceptual structure. Wrappers can be great tools for this purpose. They are structured activities in which students are required to reflect on a task, homework, or an exam, thus providing students with necessary experience to develop metacognition (Lovett, 2013). In a similar vein, teachers can use wrappers to enhance metaconceptual components during or after conceptual change process. Furthermore, teachers can use group discussions, class discussions, concept mapping, journal writing, poster preparation, or predict-observe-explain tasks to enhance metaconceptual awareness and regulation (Rickey & Stacy, 2000; Yuruk et al., 2011). Importantly, instruction that is based on inquiry can provide opportunities for students to become aware of and regulate their conceptions because during inquiry learning students take greater responsibility for their own learning as also stated in other studies (e.g. Kipnis & Hofstein, 2008; Rickey & Stacy, 2000; Schraw, Crippen, & Hartley, 2006; Zhang, Hsu, Wang, & Ho, 2015). In addition, inquiry-based environments provide students the opportunity to question the appropriateness of their existing knowledge and therefore open a way for conceptual change. Schraw et al. (2006) indicated that an inquiry-based learning environment promoted students' metacognition since students took part in metacognitive processes during scientific inquiry. Kipnis and Hofstein (2008) reported that an inquiry-based laboratory in chemistry provided students the opportunity to practice their metacognitive skills. In line with Kipnis and Hofstein's (2008) claim, teachers can increase their students' metaconceptual awareness and regulation through inquiry laboratory activities. Chemistry laboratories in which students form and test their hypotheses, plan their work, experience cognitive conflict so that they review and revise their ideas, draw conclusions and construct scientific explanation of phenomena have potential to encourage students to engage in metaconceptual awareness and regulation. Another way to facilitate metaconceptual awareness and regulation is through the use of technology (Azevedo, 2005; Kelly, 2014; Lee, Irving, Pape, & Owens, 2015; Mair, 2012). In line with Azevedo's (2005) claim that computers can be metacognitive learning tools, we can use computer environments to reinforce opportunities to engage with metaconceptual components. Findings of these studies suggest that teachers can offer scaffolded instruction through hypermedia, tutoring system, or simulations in which students set goals, activate their previous ideas, evaluate their conceptions, and elaborate on changes in the conceptions. Using these kinds of instruction, teachers should value students' use of metaconceptual components while they are engaging in learning as a conceptual change process (Yuruk et al., 2009).

Metaconceptual activities have profound impacts on one's conceptual system and more research is warranted on metaconceptual aspects of learning. Findings for this study resulted in several suggestions for future research. First of all, further validation studies with students from different grade levels and cultures are needed. Second, results obtained from MARS should be supported by data from qualitative studies, and researchers could develop interview protocols considering the results coming from the scale. Finally, future research should investigate relationships between students' use of metaconceptual awareness and regulation and other cognitive and affective variables. Overall, focusing on metaconceptual components like those in the MARS instrument have the potential to not only fill gaps in the literature but to provide promising tools for assessing students' metaconceptual awareness and regulation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1. The Metaconceptual Awareness and Regulation Scale (MARS)

Direction: This scale aims to understand your ideas related to learning. While answering this scale, please focus on your learning about a chemistry topic. Please read each statement and circle only one number reflecting your opinion. There are no right or wrong answers. Your answers will be kept confidential. Thank you for your participation.	Never	Rarely	Occasionally	Frequently	Very frequently	Always
1. While learning chemistry topics, I compare whether my ideas are consistent with the ideas coming from my friends, teacher or other sources (book, journal, etc.)	1	2	3	4	5	6
2. While learning a chemistry topic, I monitor the changes in my ideas related to the/that topic.	1	2	3	4	5	6
3. I consider if I can use the knowledge I learned recently in the chemistry course in various topics.	1	2	3	4	5	6
4. I question whether my prior knowledge related to a chemistry topic is plausible.	1	2	3	4	5	6
5. I know what I did *not* understand about a chemistry topic.	1	2	3	4	5	6
6. I know what I learned about a chemistry topic.	1	2	3	4	5	6
7. While learning a chemistry topic, I compare my prior knowledge with the new knowledge.	1	2	3	4	5	6
8. I use my prior knowledge related to a chemistry topic.	1	2	3	4	5	6
9. I become aware that I understood a topic related to chemistry.	1	2	3	4	5	6
10. I evaluate whether the ideas coming from my friends, my teacher, or other sources (book, journal, etc.) related to a chemistry topic are plausible or not.	1	2	3	4	5	6