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Perceived autonomy-support, expectancy, value, metacognitive strategies and performance in chemistry: a structural equation model in undergraduates

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Research in chemistry education has highlighted a number of variables that predict learning and performance, such as teacher-student interactions, academic motivation and metacognition. Most of this chemistry research has examined these variables by identifying dyadic relationships through bivariate correlations. The main purpose of this study was to simultaneously investigate students' perceptions of teacher-student interactions (autonomy support), motivation (expectancy, importance, utility and interest), metacognitive strategies for problem solving (planning, monitoring and evaluation), and performance in chemistry. Measures were collected from 503 Spanish undergraduates (53.13 % females) aged 18 to 36 years. Structural equation modeling (SEM) tested the hypothesized direct and mediated relations between these variables. First, confirmatory factor analysis (CFA) provided evidence of the robustness of the evaluation instruments. Second, perceived autonomy support positively predicted expectancy, importance, utility, interest, planning, monitoring, evaluation and performance in chemistry; motivational variables positively predicted metacognitive strategies and performance; and metacognitive strategies positively predicted performance. Moreover, all hypothesized mediated effects between variables were also supported. We conclude discussing the main findings of this study, highlighting their educational implications, acknowledging their limitations, and proposing lines of future research on chemistry education.

Introduction

At secondary school level, science in general and chemistry in particular have both been continually described as being challenging and difficult subjects among students, as contended by Stuckey *et al.* (2013), Thomas and McRobbie (2013) and Villafañe *et al.* (2014). Nevertheless, introductory college-level chemistry courses are a requirement for students on many degree courses (Xu *et al.*, 2013; Ferrell and Barbera, 2015). In the same line, Cook *et al.* (2013, p. 961) assert that "college students often find general chemistry to be a very challenging rite of passage on their way to degrees in various science, technology and mathematics disciplines". As Ferrell and Barbera (2015) emphasize, the combination of content difficulty and the fact that students are fulfilling a credit requirement for their non-chemistry majors generate that students struggle through chemistry and are unsuccessful in this discipline. Thus, university chemistry lecturers should be encouraged to motivate and implicate students to ensure they achieve the highest learning and performance levels.

In the Spanish university system, chemistry is a compulsory introductory subject in a broad range of degrees in several fields of knowledge, in particular the sciences (*e.g.*, Biology, Physics or Environmental Sciences), Mathematics, and degrees in technology (*e.g.*, Electrical, Mechanical or Electronic Engineering). In most of these degrees, introductory chemistry is the only compulsory chemistry related subject, which contrasts with the syllabi of other degrees such as Chemistry and Chemical Engineering.

Many factors have been reported to influence students' performance in chemistry (Juriševič *et al*., 2012; Vaino *et al*., 2012; Xu *et al*., 2013; Ferrell and Barbera, 2015). Besides cognitive factors (such as prior conceptual knowledge or mathematical ability), non-cognitive factors (such as motivation, engagement or learning strategies) are extensively studied in chemistry education as potential determinants of students' learning and achievement. The expectancy-value model of motivation (Wigfield and Eccles, 2000; Eccles and Wigfield, 2002; Eccles, 2011) is a relevant proposal to explain performance in educational science (see Bøe *et al*., 2011; Chow *et al*., 2012; Velayutham and Aldridge, 2013; Abraham and Barker, 2015). Eccles and Wigfield propose that expectancy and different components of task-value (importance, interest and utility) explain and predict choice, engagement, and performance in academic contexts. Wigfield *et al*. (2009) also assert that a determining factor of expectancy and value are the "students' perceptions of socializers", i.e., teacher-students interactions provide feedback about the importance and usefulness of different activities, which can influence students' valuing of them.

The aim of this study was to examine the relationships among three key factors - classroom interactions, expectancy and value motivation, and problem solving metacognitive strategies- and their effects on the chemistry performance of undergraduates. These factors have been shown to be good predictors of achievement in previous studies of similar contexts (Chow *et al.*, 2012; Eccles and Wang, 2012; Xu *et al*., 2013). In addition, these variables have practical implications for science education, since effective instructional strategies can be implemented in chemistry classrooms to influence these factors (Xu *et al*., 2013).

Expectancy-value model

Expectancy and value are the basic constructs of Eccles and colleagues' model of motivation (Wigfield and Eccles, 2000; Eccles and Wigfield, 2002; Eccles, 2009; Wigfield *et al.*, 2009; Eccles and Wang, 2012). *Expectancy* (also named expectancy for success or expectation of success) is defined as the individuals' beliefs about how well they will do on an upcoming task, either on the immediate or longer term future. Eccles and Wigfield state that expectancy of success is measured in a manner similar to perceived self-efficacy and self-concept.

Task value (or subjective task value) is, in addition to expectancy, the main variable in the expectancy-value model (Wigfield and Eccles, 2000; Eccles and Wigfield, 2002; Wigfield *et al.*, 2009).These authors distinguish several components of task value: interest, importance, utility, and cost. Eccles and cols. defined *interest* value (or intrinsic value) as the inherent pleasure and enjoyment one gets from performing the activity, or the subjective interest the individual has in the subject. This component of task-value is conceptually close to personal interest (Ainley and Ainley, 2011; Krapp and Prenzel, 2011; Logan and Skamp, 2013), intrinsic motivation (Black and Deci, 2000) or curiosity (Bathgate *et al*., 2013). *Importance* refers to the attainment value of doing well in a task, and is linked to the relevance of engaging in a task to confirm salient or important aspects of one's identity and self-schema. This component of value is similar to the constructs of appreciation and identity (Bathgate *et al*., 2013), relevance (Assor *et al*., 2002; Stuckey *et al*., 2013; Stuckey and Eilks, 2014), and possible selves (Bøe *et al*., 2011). *Utility* value or usefulness refers to how a task relates to other personally central goals, such as future plans or occupational and career goals, even if the student is not interested in that task for its own sake. According to Eccles and Wigfield, utility value is similar to the construct of introjected regulation and instrumentality. Finally, *perceived cost* is conceptualized in terms of all the negative aspects of engaging in the task.

Numerous studies have applied the Eccles and Wigfield expectancy-value model in science and mathematics education. The main findings indicate a positive relationship of expectancy and task value components (interest, importance and utility) with engagement and performance in different academic subjects (Eccles, 2009; Wigfield *et al*., 2009; Bøe *et al*., 2011; Chow *et al.*, 2012; Eccles and Wang, 2012; Schukajlow *et al*., 2012). However, few studies have applied the expectancy-value model to the chemistry teaching-learning process (Jang *et al*., 2012; Southam and Lewis, 2013).

Perceived autonomy support

Wigfield and Eccles (2000; Eccles and Wigfield, 2002) assert that teacher-students interactions in classrooms (perceived by students) determine expectancy of success and components of task value. Most authors of the motivational self-determination theory (SDT) operationalized some of these classroom interactions such as "perceived autonomy support" (Black and Deci, 2000; Assor *et al.*, 2002; Reeve, 2009; Jang *et al.*, 2010, 2012; Vansteenkiste *et al.*, 2012).

Reeve (2009; Su and Reeve, 2011) lists the instructional behaviors most closely associated to an autonomy-supportive style: to provide choice and nurturing inner motivational resources, such as interests, preferences or psychological needs; to offer explanatory rationales, *e.g.*, articulate the sometimes hidden usefulness underlying a teacher's request; to rely on non-controlling language; to display patience to allow students the time they need for self-paced learning to occur; and to acknowledge and accept students' expressions of negative effect. According to Assor *et al*. (2002), and Katz and Assor (2007), the first component of autonomy support involves offering students the possibility of choosing between different alternatives. The teacher who provides choice tries to create a space that allows students to realize their personal preferences, interests and goals. However, in practice the possibility of choice is only meaningful if the alternatives are relevant to the student. Likewise, for Reeve (2009) and Jang *et al*. (2010, 2012), the most effective means for facilitating relevance consisted in explicitly informing students of the importance an activity or subject for achieving their personal goals. The contrary is "autonomy-suppressing teacher behaviors" (Assor *et al.*, 2002) or "psychologically controlling teaching" (Soenens *et al*., 2012), that occurs when teachers use their own opinion and values as an exclusive frame of reference and ignore their students' perspective.

Previous research confirmed autonomy support (and other "student-centered" forms of teaching) facilitated academic performance and engagement (Assor *et al*., 2002; Jang *et al.* 2010, 2012; Roorda *et al*., 2011; Juriševič *et al*., 2012; Schukajlow *et al*., 2012; Vansteenkiste *et al*., 2012). Notwithstanding, few studies have analyzed autonomy support in science education (Jang *et al.*, 2012; Velayutham and Aldridge, 2013), and in chemistry education (Black and Deci, 2000; Juriševič *et al*., 2012; Southam and Lewis, 2013). Moreover, research examining the relationships of autonomy support with expectancy and the components of task value is scant (Chouinard *et al.*, 2007; Velayutham and Aldridge, 2013).

Metacognition and chemistry

Most recent studies have focused on the role of metacognition in science learning and problem solving (Davidson and Sternberg, 1998; Schraw *et al*., 2006; Sinatra and Taasoobshirazi, 2011; Taasoobshirazi and Farley, 2013; Thomas and Anderson, 2014; Wang, *in press*). In spite of some differences, these authors consider metacognition consists of two key dimensions that enable learners to understand (knowledge of cognition) and monitor (regulation of cognition) their cognitive processes. Furthermore, regulation of cognition contains at least three main components: planning, monitoring, and evaluation. *Planning* comprises goal setting, activating relevant background knowledge, selecting appropriate strategies for learning, and budgeting time; includes thinking about what one needs in order to accomplish a goal and about how one intends to achieve that goal. *Monitoring* involves the self-testing skills necessary to control the process of learning, ensuring things make sense within the accepted cognitive frameworks, judging whether understanding is sufficient, and searching for connections or conflicts with what is already known. *Evaluation* refers to appraising the products and processes of learning i.e., it is the ability to assess the fruitfulness of the learning strategies one adopts. Some authors consider these self-regulatory strategies as a modality of academic engagement. Thus, according to Cleary and Zimmerman (2012), cognitive engagement includes a continuum ranging from low cognitive engagement (use of shallow processing strategies) to high metacognitive engagement (deep processing strategies).

Otherwise, the ability to correctly set up and solve complex chemistry problems is critical for success at multiple levels of chemistry courses (Scherer and Tiemann, 2012). Most of the tasks students complete in chemistry courses in class, for homework, and on tests involve setting up and solving problems (Taasoobshirazi and Glynn, 2009; Taasoobshirazi and Farley, 2013). Though there is no overall consensus among authors as to the stages involved in the problem solving process, it begins with reading and comprehension of the problem, and it concludes with the analysis of the results obtained. Studies on problem solving have tended to compare experts with novices in this task (Taasoobshirazi and Glynn, 2009; Schukajlow *et al*., 2012; Taasoobshirazi and Farley, 2013). These authors assert that the techniques and strategies necessary for expert problem solving are quite complex, and a large number of students fail to develop them spontaneously. The differences between experts and novices involve (among other aspects) the use of metacognitive strategies, a variable affecting students' ability to transfer solution steps to unknown problems (Scherer and Tiemann, 2012).

In science in general, and in chemistry in particular, the metacognitive and self-regulatory strategies have been shown to be useful for enhancing the study and learning process (Schraw *et al*., 2006; Sinatra and Taasoobshirazi, 2011; Cook *et al*., 2013; Lopez *et al*., 2013; Thomas and McRobbie, 2013; Mathabathe and Potgieter, 2014; Thomas and Anderson, 2014; Wang and Chen, 2014), the laboratory practices (Sandi-Urena *et al*., 2011b, 2011c, 2012), and the problem solving processes (Davidson and Sternberg, 1998; Cooper and Sandi-Urena, 2009; Sandi-Urena *et al*., 2011a; Siburt *et al*., 2011; Scherer and Tiemann, 2012; Taasoobshirazi and Farley, 2013; Wang, *in press*).

A research instrument used to assess students' metacognitive skills at solving problems is the Physics Metacognition Inventory (PMI), designated and validated by Taasoobshirazi and Farley (2013). This instrument provides information about students' metacognitive activity during problem solving and identifies where students may be failing to understand or regulate their problem-solving process. The PMI includes 24 items grouped into six factors: knowledge of cognition, information management, debugging, planning, monitoring, and evaluation.

Relationships between variables

As Brandriet *et al*. (2013) recognize, educational research has typically examined motivation, metacognition and performance by identifying dyadic relationships through the use of bivariate correlations and/or associations between variables applying regression techniques. As an example, Black and Deci (2000) found, in studies with undergraduates in a workshop chemistry project, that perceived autonomy support positively correlated with perceived competence in being successful in chemistry, interest and enjoyment in this subject, and performance (average exam scores and final grade). In another study, Sierens *et al*. (2009), with undergraduate and secondary school students, found that perceived autonomy support positively correlated with self-regulated learning strategies in maths, languages and sciences.

In contrast to these correlational studies, some research applied structural equation modeling (SEM), a multivariate data analysis approach used to investigate complex relationships among multiple variables (Byrne, 2010; Xu *et al*., 2013). For instance, Soenens *et al*. (2012), in a study with grade 11 and 12 Belgian adolescents referring to "teachers" in general, reported that perceived psychologically controlling teachers negatively predicted students' autonomy for studying, self-regulatory strategies, and overall grades; furthermore, motivation and metacognitive strategies mediated the negative influences of a controlling teacher on performance.

SEM was also applied in science and math education. For example, Chouinard *et al.* (2007), with Canadian year 7 to 11 students, reported that perceived teachers' support positively predicted competence beliefs, utility value, and effort they put in learning mathematics; competence and utility fully mediated the relations from perceived teachers' support to effort. In a longitudinal study by Jang *et al.* (2012) with grade 8 Korean students for biology, geology or earth sciences, academic motivation and engagement mediated the positive relationships from perceived autonomy support to final grades. Similar results were obtained by Velayutham and Aldridge (2013) with Australian science students in grades 8, 9 and 10; the main findings indicated that teacher support positively predicted interest, importance, and utility value; self-efficacy and task value positively predicted self-regulatory strategies in science class; and both self-efficacy and task value fully mediated the positive effect from teacher support to self-regulatory strategies. Recently, Abraham and Barker (2015) reported that expectancy, interest and utility predicted sustained engagement and enrolment intentions in physics; furthermore, academic engagement mediated the effects from expectancy and value to enrolment intentions.

Finally, some studies in chemistry education also applied SEM. Among them, Taasoobshirazi and Glynn (2009) found chemistry self-efficacy positively predicted students' problem-solving strategies, and both (self-efficacy and strategies) predicted the number of problems correctly solved; moreover, problem-solving strategies mediated the positive effect from self-efficacy to problem solution. In another study, Xu *et al.* (2013) reported that math ability, attitude toward chemistry and prior conceptual knowledge positively predicted achievement in a general chemistry course in undergraduates. Brandriet *et al.* (2013) also revealed the positive effects of attitudes toward chemistry on performance in this subject. Recently, Cheung (2015) found that teacher support (efficacy-enhancing teaching) positively predicted deep learning strategy use and chemistry self-efficacy; besides, learning strategies mediated the influence of teacher support on chemistry self-efficacy.

Present study

As the foregoing discussion indicates, teacher-student interactions, academic motivation, metacognitive strategies and their relationships with performance in chemistry have been examined previously, but mostly in separate studies (Xu *et al*., 2013). The present work simultaneously investigated the relationships among students' perception (perceived autonomy support), motivation (expectancy, importance, utility and interest), metacognitive strategies for problem-solving (planning, monitoring and evaluation), and performance. This study also used SEM, a statistical technique not yet commonly used in research on chemistry education, to test the adequacy of the instruments applied, and to assess the direct and mediated relations between variables. Furthermore, the present study is not only strongly grounded in previous literature, but is also supported by a theoretical framework which upholds the hypothesized model of relations among variables, a crucial characteristic for formulating a SEM model according to Brandriet *et al*. (2013) and Velayutham and Aldridge (2013).

The theoretical framework for the present study was based on the expectancy-value model proposed by Wigfield and Eccles (2000), Eccles and Wigfield (2002), and Wigfield *et al*. (2009).These authors posit that students' academic motivation (*e.g.*, expectancy, importance, utility and interest) is influenced by their personal perceptions of classroom interactions (*e.g.*, perceived autonomy support), and determine their levels of engagement (*e.g.*, planning, monitoring and evaluation), and achievement (*e.g.*, grade in chemistry). An equivalent model of relations among motivation and self-regulated learning of college chemistry was suggested by Zusho *et al.* (2003). Likewise, the models of relations tested by previously cited researchers of autonomy support (see Jang *et al.*, 2012 and Soenens *et al.*, 2012) are quite similar to the expectancy-value model. The hypothesized paths between variables in the present study are depicted in Fig. 1. Moreover, most of the research previously reviewed provides evidence for these proposals.

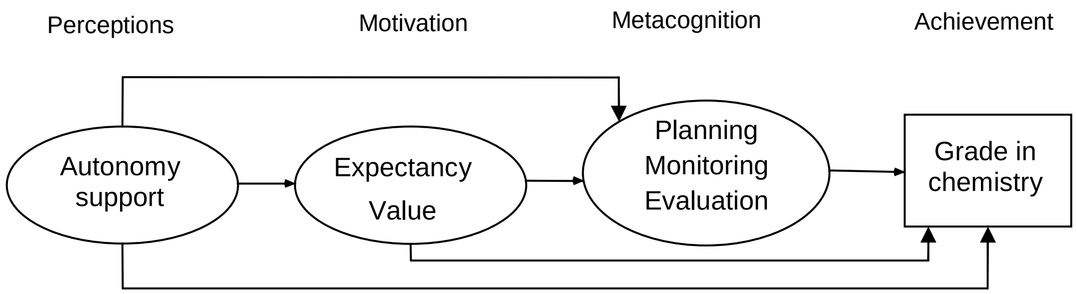

Fig. 1 The hypothesized model of relations among variables

As shown in Fig. 1, the model proposes that perceived autonomy support predict expectancy and value components, which, in turn, predict differences in metacognition (planning, monitoring, and evaluation) that subsequently predict academic performance. Therefore, the research hypotheses tested by the implementation of SEM are: (1) Perceived autonomy support would positively predict motivation, metacognitive strategies and performance.(2) Expectancy, importance, utility and interest would positively predict metacognitive strategies and performance.(3) Planning, monitoring and evaluation would positively predict performance. (4) The influence of expectancy and value on grades would be mediated by metacognitive strategies. (5) Motivational variables and metacognitive strategies would mediate the positive effects of perceived autonomy support on performance.

Methodology

Participants

A total of 503 undergraduates from state universities in North-western Spain aged 18 to 36 years (Mean = 22.4 years; SD = 2.4) took place in this study. The undergraduates were enrolled on science and technology degrees. Besides the introductory subject of chemistry, these degrees do not contain many compulsory subjects related to chemistry. The introductory course on chemistry was taught either in the 1st or 2nd semester. All of the undergraduates had enrolled for the first time on this introductory chemistry course, and most were first or second-year undergraduates. As for gender, the 53.13% of the sample were women.

Permission to gather data was obtained from all appropriate university authorities. Participants were informed about the aim of the current study. All undergraduates voluntarily took part in the study and no incentives or extra credits were given for their participation. Students were guaranteed strict anonymity and confidentiality and were assured that the results would not impact on their grades.

Instruments

Autonomy support. The students' perception of teacher autonomy support was evaluated using a subscale taken from the *Teacher as Social Context (TaSC)* questionnaire, proposed by Belmont, Skinner, Wellborn and Connell (1992), which consisted of four items. Two *choice* items evaluated the degree to which students perceived a teacher offered different alternatives to carry out academic activities (*e.g.*, "My chemistry teacher gives me many options for doing my tasks"). On the two *relevance* items, students measured how the chemistry teacher communicated the importance and usefulness of the content that was taught (*e.g.*, "My chemistry teacher talks about how we can use the things we learn in class"). Students scored each item on a five-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree).* A confirmatory factor analysis of the scale revealed the one factor model adequately fitted the data (χ^2 (2, N = 503) = 2.57 p> 0.276*;* χ^2/df = 1.28; GFI = 0.997; CFI = 0.998; RMSEA = 0.024).

Expectancy. In previous studies, this variable was evaluated using expectancy and ability (or competence) related items (Eccles and Wigfield, 1995; Wigfield and Eccles, 2000). Thus, in this study expectancy was evaluated using four items selected from these authors, two of which evaluated competence/ability beliefs (*e.g.*, "Compared to most of your other subjects, how good are you at learning chemistry? 1 = *Not at all good*; 5 = *very good*"). The remaining two items evaluated expectancy beliefs (*e.g.*, "How well do you expect to do in chemistry this year? 1 = *Not at all well*; 5 = *very well*").

Task value. To assess the components of task value, the *Perceived Task Value Scale* (Eccles and Wigfield, 1995) was administered consisting of six items, two for each positive component of value: interest, importance and utility value. For example, an item measuring *interest* was "In general, how much do you like doing chemistry assignments in college …", and the responses ranged from 1 (*a little*) to 5 (*a lot*). An example of an item on *importance* was "Compared to your other subjects, how important is it for you to be good at chemistry?", ranging the responses from 1 (*not at all important*) to 5 (*very important*). An item on *utility* was "How useful do you think college chemistry is for what you want to do after you graduate and go to work?", with responses ranging from 1 (*not very useful)* to 5 (*very useful*).

Metacognitive strategies. To assess metacognitive strategies in chemistry problem solving, three scales of Regulation of Cognition taken from the Physics Metacognitive Inventory (Taasoobshirazi and Farley, 2013) were adapted and applied. The scale of *planning* consisted of five items (*e.g.*, "I think about what chemistry problem is asking before I begin to solve it" or "Before I start solving a chemistry problem, I plan out how I am going to solve it"). The scale of *monitoring* included four items (*e.g.*, "While solving a chemistry problem, I periodically evaluate how well I am doing" or "While solving a chemistry problem, I ask myself if I am meeting my goals"). The scale of *evaluation* contained three items (*e.g.*, "I go back and check my work after solving a chemistry problem" or "After solving a chemistry problem, I look back to see if I did the correct procedures"). Responses were rated on a 5-point scale from 1 (*totally disagree*) to 5 (*totally agree*).

Academic performance. As an objective indicator of academic performance in chemistry the student's final year score, an aggregate measure of students' achievement throughout the academic year was used. Scoring ranged from 1 (*very deficient*) to 10 (*excellent*). The pass mark was a score ≥ 5. The final score was estimated on the basis of the results of a final exam and, to a lesser extent, of homework (mainly problem solving tasks) and participation in classroom activities and laboratory sessions.

All of the analyses of the present study were undertaken on the entire sample of students (n = 503) i.e., both students who had failed (grade < 5) and those who had passed (grade ≥ 5).

Procedure

The questionnaires were administered throughout the 4-month chemistry course: undergraduates responded to the perceived instrumentality and motivational scales during the fifth week of class, and the metacognitive scale three weeks before ending the course; finally, each student informed of their final grade at the end of the course.

The course lasted for approximately four months. After five weeks (25 class-contact hours), students had already made their own perceptions of teacher's autonomy support. By two or three weeks before the end of the course, students had undertaken a wide array of chemistry assignments (seminars, homework, and preparation for their final exam); for this reason it was decided to evaluate the application of self-regulating strategies at that given moment in time.

Outline of data analyses

In this study, statistical analysis initially determined the reliability coefficients (Cronbach's alpha) and the descriptive statistics using the SPSS 22 statistical package. As a second step, confirmatory factorial analysis (CFA) of the scales was then undertaken, using the AMOS 22 software (Arbuckle, 2013), to validate the questionnaires used in this study. Finally, a structural equation model (SEM) was performed to test the proposed mediational model.

SEM is a robust statistical data analysis approach applied to study complex relationships among variables. The typical research questions that can be answered using SEM are how multiple variables interact with one another. This analysis provides a more complete portrait of the relationships among the observed and latent variables (Byrne, 2010).

In educational sciences, researchers are often interested in studying theoretical constructs that are often inaccessible to direct measurement. These abstract phenomena are termed latent variables, latent factors or constructs. Because of these characteristic of latent variables, the researchers must link them to one that is observable, thereby making the measurement possible. The assessed scores are termed observed variables, manifest variables or indicators.

SEM explicitly recognizes that the latent variables are possibly measured by multiple indicators, and consists of two major parts, a measurement model and a structural model. The first is a CFA to test the robustness of the applied instruments. The structural model displays the paths in the hypothesized model as a succession of structural equations. In a path diagram, traditionally squares or rectangles represent observed variables, and the latent variables are depicted graphically with circles or ovals.

The CFA and SEM model fit was evaluated by the following indices (Byrne, 2010): the χ^2, the main index for evaluating the global significance of a model, though it is very sensitive to sample size in complex models; the indicator χ^2/df, which is considered to be acceptable when values are below 5; the Comparative Fit Index (CFI) and the Normed Fit Index (NFI) with values above 0.90; and the Root Mean Square Error of Approximation (RMSEA) with values ranging from 0.08 to 0.05 or less, which are considered to be reasonable. These fit indexes are among the most widely reported in the SEM literature. See, for example Stamovlasis *et al.* (2012), Brandriet (2013), Xu *et al.* (2013), Villafañe *et al.* (2014) or Salta and Koulougliotis (2015) for recent applications of SEM analysis to chemistry education.

According to these and other authors (Byrne, 2010; Tomarken and Waller, 2005), SEM has several advantages over other methods: they allow for the analysis of statistically non-normal data; enable theoretical knowledge to be introduced into model specification; can test phenomena assessing multiple endogenous and exogenous variables; use latent variables, each of which is evaluated by multiple indicators; and they take into account the role of mediating variables and not just the direct influence of one variable on another.

Mediation analysis attempts to identify an intermediary process (mediator) that leads from the independent (exogenous, antecedent or predictor) variable to the dependent (endogenous, outcome or criterion) variable. In other words, in a simple mediational model, the independent variable is presumed to influence the mediator, and in turn, the mediator influences the dependent variable. For this reason a mediation effect is also termed as indirect effect, surrogate effect, intermediate effect or intervening effect (Wu and Zumbo, 2008). A direct effect represents the influence of an independent variable on a dependent variable unmediated by another variable in the model. An indirect effect represents the influence of an independent variable on a dependent variable through a mediator. The total effect is the summation of the direct effect plus the indirect effect. As an example for a mediation model, undergraduates' expectancy of success (i. e., independent variable) is hypothesized to affect students' academic engagement (i.e., mediator), and in turn academic engagement affects the outcome of academic performance (i.e., dependent variable). In educational sciences, frequent questions suggest a similar chain of relations where an antecedent variable affects a mediating variable, which ten exert an influence on an outcome variable.

Mediation may be full (perfect, complete) or partial. A partially mediated relationship occurs when the effect of the mediator accounts for a significant amount of variance in the dependent variable, but the direct effect from the independent to dependent variable remains significant (Little *et al.*, 2007). In a partially mediated relationship, both the direct and the indirect effects are significant. If the relationship between variables is fully mediated, then all of the significant variance of that relationship will be accounted for by the effect from the mediator to dependent variable. A fully mediated relationship requires that the indirect effect to be significant and the direct effect to be nonsignificant. According to Little *et al*. (2007) *full* and *partial* are essentially informal effect size descriptors and, in practice, they might be viewed as an indication of the magnitude or importance of a mediation effect in explaining the total effect, yet they are traditionally defined in terms of statistical significance.

In this study, the variables were assessed over a 4-month period in order to improve the empirical adequacy of the mediational model between variables.

Results

Preliminary analysis

Table 1 shows the descriptive statistics and internal consistencies (Cronbach's α). The mean scores were highest in importance and interest; intermediate in expectancy, utility, monitoring and evaluation; and lowest in perceived autonomy support and planning.

Table 1 Descriptive statistics and Cronbach's alphas

Variable	Minimum	Maximum	Mean	SD	Alpha
Autonomy support	1.25	5.00	3.01	0.68	0.73
Expectancy	1.25	5.00	3.25	0.88	0.81
Importance	1.00	5.00	3.36	0.95	0.71
Utility	1.00	5.00	3.21	0.96	0.74
Interest	1.00	5.00	3.42	1.11	0.78
Planning	1.60	4.80	3.06	0.70	0.77
Monitoring	1.00	5.00	3.14	1.02	0.87
Evaluation	1.00	5.00	3.26	1.12	0.86
Performance	2.80	10.00	7.28	1.67	-

The values of Cronbach's alpha for the applied scales ranged in magnitude from α = 0.71 (Importance) to α = 0.87 (Monitoring) indicating that reliability was satisfactory to excellent.

In this work students were grouped according to the instructor ("teacher") of the subject of chemistry. An intraclass correlation coefficient (ICC), as proposed by Shrout and Fleiss (1979), was calculated to assess the extent to which perceived autonomy support reflect possible effects derived from "teacher". This statistic estimates the proportion of variance in the data that is due to rated subjects (i.e., students) rather than due to groups (i.e., "teacher") and residual. Their values may range from 0 to 1. A value of ICC=1 indicates that all observed variance in a variable is explained by the differences between students. In the present work, the value of ICC for perceived autonomy support was 0.967 (Confidence Interval: 0.949, 0.979) for data grouped by "teacher". On the basis of this index it would be reasonable to claim that perceived autonomy support can be considered as individual attribute given the minor involvement of the group variables ("teacher") in generating total variability.

Measurement model

In order to test the robustness of the evaluation instruments, a confirmatory factorial analysis (CFA) was performed using the AMOS 22 software (Arbuckle, 2013). The CFA had a total of eight latent variables and 26 measured variables. These measured variables were two items on importance, utility and interest; three items on evaluation; four items on autonomy support, expectancy and monitoring; and five items on planning. As shown in Table 2, all of the measured variables obtained values ranging from -0.19 to 0.34 for skewness, and from -1.26 to -0.14 for kurtosis, confirming the univariate normality assumption (Arbuckle, 2013; Byrne, 2010). The measurement model with covariances among all constructs fitted the data well, $\chi^2(289, N = 503) = 467.19$ $p < 0.001$; $\chi^2/df = 1.62$; GFI = 0.937; CFI = 0.970; RMSEA = 0.035. The mean for the indicators ranged from 2.92 (Ausu3) to 3.44 (Inter2).

Table 2 Standardized factor loadings, skewness, and kurtosis of the measurement model

Variable	Item	Mean	SD	Factor loading	Error	Skewness	Kurtosis
Autonomy support	AuSu1	2.96	0.88	0.65	0.42	0.34	-0.15
	AuSu2	3.05	0.89	0.65	0.42	0.21	-0.30
	AuSu3	2.92	0.94	0.68	0.46	0.33	-0.15
	AuSu4	3.11	0.95	0.57	0.32	0.19	-0.34
Expectancy	Expe1	3.35	1.13	0.71	0.51	0.01	-1.12
	Expe2	3.20	1.07	0.65	0.43	0.12	-0.63
	Expe3	3.19	1.04	0.75	0.57	0.04	-0.72
	Expe4	3.27	1.17	0.75	0.56	-0.07	-0.93
Importance	Impo1	3.30	1.10	0.77	0.58	-0.07	-0.78
	Impo2	3.38	1.08	0.73	0.53	0.02	-1.09
Utility	Util1	3.20	1.09	0.77	0.60	-0.17	-0.67
	Util2	3.21	1.07	0.76	0.56	-0.03	-0.71
Interest	Inter1	3.41	1.15	0.80	0.62	-0.13	-1.05
	Inter2	3.44	1.22	0.81	0.66	-0.19	-1.09
Planning	Plan1	3.00	0.98	0.69	0.46	0.10	-0.68
	Plan2	3.03	0.90	0.62	0.39	0.11	-0.63
	Plan3	3.07	0.98	0.68	0.47	0.16	-0.83
	Plan4	3.08	0.95	0.65	0.42	0.08	-0.79
	Plan5	3.10	1.01	0.55	0.30	-0.14	-0.78
Monitoring	Moni1	3.12	1.19	0.79	0.62	-0.04	-0.88
	Moni2	3.11	1.22	0.77	0.59	0.01	-0.94
	Moni3	3.14	1.24	0.84	0.71	0.09	-1.17
	Moni4	3.21	1.23	0.76	0.58	-0.03	-1.03
Evaluation	Eval1	3.19	1.22	0.78	0.61	0.01	-1.10
	Eval2	3.28	1.24	0.80	0.63	-0.01	-1.11
	Eval3	3.32	1.35	0.87	0.76	-0.15	-1.26
Performance	-	7.27	1.67	-	-	-0.53	-0.34

Note: For all items: minimum = 1, and maximum = 5.

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The standardized factor loadings represent the relationships between the observed and the latent variables and indicate how well a given item measures its corresponding factor (Byrne, 2010). In all latent variables (see Table 2), the standardized factor loadings were significant at the level of $p < 0.001$, and ranged from 0.55 (Plan5) to 0.87 (Eval3), therefore all exceed the factor-loading criterion of 0.35 (Byrne, 2010). Table 3 presents correlations between the measured latent constructs. Appendix includes the covariance matrix of the observed variables for the CFA analysis.

Table 3 Estimated correlations between latent constructs

	1	2	3	4	5	6	7	8
1. Autonomy support	-							
2. Expectancy	0.10	-						
3. Importance	0.17	0.53	-					
4. Utility	0.22	0.53	0.66	-				
5. Interest	0.08	0.58	0.77	0.60	-			
6. Planning	0.26	0.55	0.65	0.59	0.64	-		
7. Monitoring	0.27	0.60	0.69	0.65	0.67	0.49	-	
8. Evaluation	0.32	0.61	0.68	0.64	0.69	0.54	0.68	-
9. Performance	0.28	0.57	0.69	0.65	0.65	0.64	0.67	0.68

All estimated correlations between latent variables were positive. Final academic performance in chemistry significantly correlated with all assessed variables, with values ranging from $r = 0.28$ (autonomy support) to $r = 0.68$ (evaluation). All estimated correlations in Table 3 were significant ($p < 0.001$), except for the indices relating autonomy support to expectancy ($r = 0.10$; $p < 0.08$) and autonomy support to interest ($r = 0.08$; $p < 0.154$).

Structural model

Given that the measurement model fitted the data well, several SEM analyses were performed to test the structural model proposed in Fig. 1. The hypothesized model fit adequately the data, χ^2 (298, N = 502) = 680.19, $p < 0.001$; χ^2/df = 2.29; GFI = 0.912; CFI = 0.936; RMSEA = 0.051. Fig. 2 displays the overall structural model with standardized regression weights.

The analysis of the significant direct paths in the overall model showed perceived autonomy support positively predicted expectancy ($\beta = 0.15$, $p < 0.01$), importance ($\beta = 0.23$, $p < 0.001$), utility ($\beta = 0.27$, $p < 0.001$), interest ($\beta = 0.15$, $p < 0.05$), planning ($\beta = 0.14$, p <

0.05), monitoring (β = 0.14, p< 0.05), and evaluation (β = 0.21, p< 0.01). Concerning possible predictors of self-regulatory strategies, planning before problem-solving was positively predicted by expectancy (β = 0.22, p < 0.001), importance (β = 0.25, p< 0.001), utility (β = 0.19, p< 0.01), and interest (β = 0.25, p < 0.001). Similarly, the strategy of monitoring during problem-solving was also positively predicted by expectancy (β = 0.25, p< 0.001), importance (β = 0.26, p< 0.01), utility (β = 0.27, p< 0.001) and interest (β = 0.25, p< 0.01). Further, the strategy of evaluation after problem-solving was positively predicted by expectancy (β = 0.24, p< 0.01), importance (β = 0.22, p< 0.01), utility (β = 0.22, p< 0.01) and interest (β = 0.31, p< 0.001). Academic performance, assessed by final grade in chemistry, was significantly predicted by the motivational concepts of importance (β = 0.15, p< 0.01) and utility (β = 0.15, p< 0.01), and by the metacognitive strategies of planning (β = 0.25, p< 0.001), monitoring (β = 0.22, p< 0.05) and evaluation (β = 0.23, p< 0.05) of the problem-solving process.

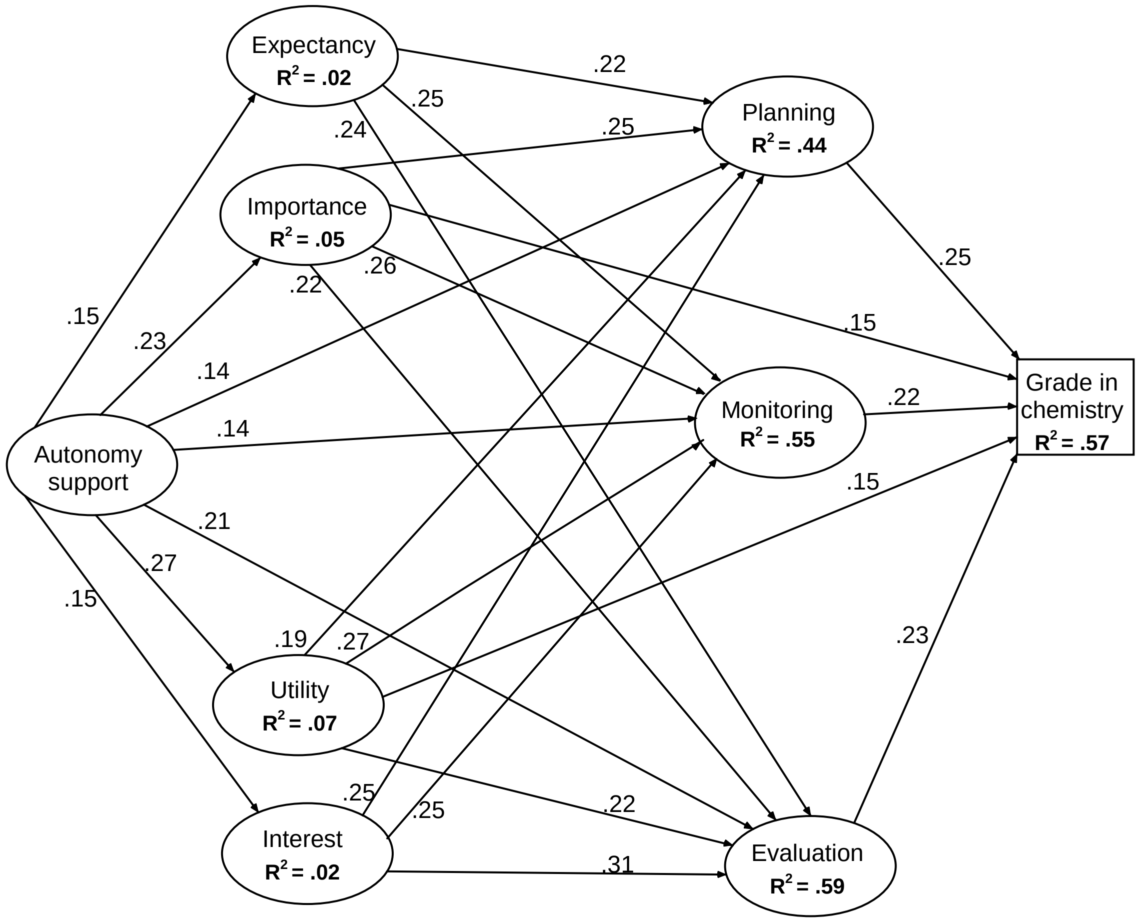

Fig. 2 Structural relations between variables (standardized regression weights)

Note: Only significant paths were represented (p < 0. 05). Circles denote latent variables. For clarity of presentation, observed variables were not drawn.

Overall, the predictor variables explained substantial proportions of variance in some outcomes, including planning (R^2 = 0.44), monitoring (R^2 = 0.55), evaluation (R^2 = 0.59) and performance (R^2 = 0.57). In the rest of outcome variables, the proportion of variance explained was lower, with R^2 = 0.07 for utility value, R^2 = 0.05 for importance, and R^2 = 0.02 for interest and expectancy.

Test for mediation

Finally, the last stage of data analyses was to establish the partial or total mediation between variables. The AMOS 22 software computes an estimation of indirect effect, and significance of a specific effect that can then be tested by bootstrapping confidence interval based on randomly selected samples (Byrne, 2010; Arbuckle, 2013). The key principle underlining the bootstrapping procedure is that it enables the researcher to simulate repeated subsamples from an original database. This resampling method allows for assessing the stability of parameter estimates, reporting their values with a greater degree of accuracy, and addressing situations where the statistical assumptions of multivariate normality may not hold (Byrne, 2010).

With regards to partial mediation, formal bootstrap tests of indirect effects confirmed that undergraduates' expectancy, importance, utility and interest significantly mediated the influence of perceived autonomy support to planning, monitoring and evaluation in problem-solving. Moreover, these three metacognitive self-regulatory strategies partially mediated the influence of importance and utility on performance.

For planning and monitoring, the results were as follows: the total effect from autonomy support to planning was significant (β = 0.313) with most of the effect being indirect (β = 0.177) than direct (β = 0.136); and the total influence of autonomy support on monitoring was significant (β = 0.348) with most of this effect being indirect (β = 0.206) than direct (β = 0.142). Similarly, the total influence of importance on performance was significant (β = 0.319) and the sum of indirect effects (β = 0.169) was higher than the direct path (β = 0.150); and the total effect from utility to performance was significant (β = 0.309) and the magnitude of the indirect effects (β = 0.157) was higher than the direct effect (β = 0.152). Finally, the total path from autonomy support to evaluation was significant (β = 0.401) and the direct effect (β = 0.206) was more intense than the sum of indirect effects (β = 0.195). In all of these cases, the direct and indirect effects were significant (see the top of Table 3), which implies partial mediation between variables.

Table 3 Effects on planning, monitoring, evaluation, and performance

Predictor → Criterion	Direct effect (p)	Indirect effect Sum (p) [a]	Indirect effect CI [b]	Total effect [c]
Partial mediation				
Autonomy S. → Planning	0.136 (0.01)	0.177 (0.01)	0.058, 0.315	0.313
Autonomy S. → Monitoring	0.142 (0.01)	0.206 (0.01)	0.073, 0.355	0.348
Autonomy S. → Evaluation	0.206 (0.01)	0.195 (0.01)	0.064, 0.337	0.401
Importance → Performance	0.150 (0.01)	0.169 (0.01)	0.071, 0.294	0.319
Utility → Performance	0.152 (0.01)	0.157 (0.01)	0.094, 0.235	0.309
Total mediation				
Autonomy S. → Performance	0.001 (0.98)	0.323 (0.01)	0.210, 0.438	0.324
Expectancy → Performance	0.001 (0.94)	0.167 (0.01)	0.099, 0.244	0.168
Interest → Performance	0.001 (0.95)	0.187 (0.01)	0.088, 0.297	0.188

Notes: ([a]) The probability associated to the sum of standardized indirect effects was estimated using the two-sided bias-corrected confidence interval bootstrap test of AMOS 22 (confidence level = 95%; samples = 5.000). ([b]) CI = Confidence Interval. ([c]) All the total effects were significant (p< 0.001).

As for the total mediation, planning, monitoring, and evaluation fully mediated the relationships that linked expectancy and interest to performance. Moreover, motivational variables and metacognitive strategies mediated the intense and positive association between autonomy support and performance. For these variables, the results were as follows: the total effect from autonomy support to performance was significant (β = 0.324), the sum of indirect effects was significant (β = 0.323) whereas the direct path was small and not significant (β = 0.001); similarly, as for the influence of expectancy on performance, the total effect (β = 0.168) and the sum of indirect effects (β = 0.167) were significant, whereas the direct path was not significant (β = 0.001); analogously, as regard to the total and significant association of interest to performance (β = 0.188), only the sum of indirect effects was significant (β = 0.187), whereas the direct path was not significant (β = 0.001). In all of these cases the indirect and total effects were significant, but the direct effects were not significant (see the bottom of the Table 3), which indicates full mediation between variables.

Discussion

As Bathgate *et al*. (2013, p. 210) recognized, different motivational theories rarely were measured simultaneously, and therefore not a great deal is known about the relationships among constructs across theories. The present study assessed perceived autonomy support, a motivational concept proposed by the SDT theory, and the variables of the expectancy-value model of motivation. The findings corroborated some results of previous research and provided fresh data for improving our understanding of the relationships between teacher-student interactions, expectancy, importance, utility, interest, self-regulatory strategies, and performance in chemistry in a sample of undergraduates.

The first step was to assess the adequacy of the questionnaires that were applied given that they had not been previously used for the subject of chemistry. The reliability coefficients were adequate, the measurement model obtained good fit indexes, and the correlations between variables were as expected, in line with several of the authors of the scales (Belmont *et al.*, 1992; Eccles and Wigfield, 1995; Wigfield and Eccles, 2000; Taasoobshirazi and Farley, 2013).

Moreover, a SEM analysis of the relations between variables simultaneously estimated the relationships among variables so that each variable competed for shared variance with other variables in the model (Brandriet *et al*., 2013). In other words, each variable in the model was influenced by (and influenced) the system of variables that surrounded it.

Direct relationships

In the present study, perceived autonomy support enhanced expectancy, importance, utility and interest. This finding is in line with the scant research on the relationships of autonomy support with expectancy and the components of task value (Chouinard *et al.*, 2007; Velayutham and Aldridge, 2013). However, in the present study, the positive effects from autonomy support to expectancy and value variables were higher for perceived importance and utility, and lower for expectancy and interest. These findings suggest that students' perception of autonomy supportive teaching enhanced specially the personal importance assigned to chemistry and the utility value. The influence of perceived autonomy support on expectancy of results and interest was significant, but low.

Furthermore, perceived autonomy support positively predicted self-regulatory metacognitive strategies. In the present study, undergraduates who perceived their teachers had offered them more autonomy-supportive interactions also planned, monitored and evaluated more the chemistry problem-solving process. This finding is in accordance with the results obtained by Sierens *et al.* (2009), who evaluated autonomy support and self-regulatory strategies in mathematics, languages, and educational sciences; in the same line, psychologically controlling teachers negatively predicted self-regulated learning strategies (Soenens *et al.*, 2012).This finding also agree with Sinatra and Taasoobshirazi (2011) who assert that teachers can promote self-regulation in science students in order to improve their success in solving scientific problems and engaging in critical thinking.

Some previous research found positive relationships between the use of metacognitive strategies and different motivational constructs, such as perceived autonomy for studying (Soenens *et al.*, 2012), self-efficacy, interest, utility and importance (Velayutham and Aldridge, 2013) in secondary students. In the present study we find that undergraduates with higher scores on expectancy, importance, value and interest applied more frequently planning, monitoring and evaluation in chemistry problem-solving. These findings corroborated the results obtained in other subjects and in other age populations.

As expected, problem-solving metacognitive strategies predicted final performance in chemistry. This finding suggests that the undergraduates who best planned, monitored and evaluated the process of chemistry problem-solving also obtained higher grades in this subject. These findings agree with previous research in which metacognition enhanced chemistry learning (Thomas and McRobbie, 2013; Mathabathe and Potgieter, 2014; Thomas and Anderson, 2014), achievement in chemistry lab activities (Sandi-Urena *et al*., 2011b, 2011c) and results in chemistry problem-solving (Cooper and Sandi-Urena, 2009; Sandi-Urena *et al*., 2011a; Scherer and Tiemann, 2012).

Mediated relations

Perhaps one of the most innovative contributions of the present study refers to the mediated relations between the variables. Thus, the influence of perceived autonomy support on metacognitive strategies was mediated by expectancy and value: undergraduates who perceived their teachers supported their autonomy in class, also planned, monitored and evaluated more the chemistry problem-solving process (in part) because they felt they were capable of passing the subject, believed it was useful and important, and enjoyed it.

As hypothesized, perceived autonomy support also positively predicted academic performance, in line with Assor *et al*. (2002), Jang *et al.* (2010, 2012), Roorda *et al.* (2011), Juriševič *et al*. (2012), Schukajlow *et al*. (2012), and Vansteenkiste *et al*. (2012). However, in the present study the intense and positive association between autonomy support and performance (β = .343) were mostly mediated through motivational and metacognitive variables: undergraduates with higher perceived autonomy support obtained better grades in chemistry because they thought they were capable of passing the subject, valued it more, and applied more often metacognitive strategies in chemistry problem-solving. This intense mediated effect might explain the low bivariate correlations between autonomy support and achievement obtained, for example, by Jang *et al*. (2012), with correlational values ranging from r = .13 to$r$ = .17.

With regard to the associations between motivational variables and performance, the direct and indirect effects were significant for importance and utility value, suggesting the existence of partial mediation. In comparison, the direct effects of expectancy and interest were not significant whereas the indirect effects were, indicating total mediation. In both cases (for partial and total mediation), a considerable portion of the intense and positive influences of expectancy and value variables on performance were explained because undergraduates with higher levels of expectancy, importance, utility and interest toward chemistry also applied more often self-regulatory metacognitive strategies in chemistry problem-solving, which enhances final performance. Analogous mediational findings were obtained by Taasoobshirazi and Glynn (2009) and Soenens *et al*. (2012) for problem solving strategies, and by Chouinard *et al*. (2007), Jang *et al*. (2012) and Velayutham and Aldridge (2013) for motivational variables. These findings also corroborate the relationships between variables proposed by the expectancy-value model (Eccles and Wigfield, 2002) which support the SEM hypothesized in the present study.

Educational implications

Identifying variables that explain and predict the choice of an activity, the levels of engagement in carrying it out, and performance in achieving the outcome is a major challenge for teachers in order to guide decisions about which interventions could be effective in improving student achievement (Eccles, 2011). All of these interventions are grounded on the assertion of Schraw *et al*. (2006) and Sandi-Urena *et al*. (2011a) that it is feasible to improve students' metacognition and academic motivation *via* classroom instruction

With the purpose of enhancing the students' perception of autonomy support, Reeve (2009) and Su and Reeve (2011) recommend teachers should try: to avoid controlling feelings, language and behavior; to become increasingly aware of the factors that push and pull them -intentionally or unintentionally, consciously or unconsciously- toward a controlling style; deeply appreciate the benefits of autonomy support, recognizing the ineffectiveness of other styles such as controlling and permissive; trying to take the students' perspective and welcome students' thoughts, feelings and behavior; support and promote students' motivational development and capacity for autonomous self-regulated learning; to become aware of, develop, and refine the interpersonal skills and instructional strategies that actualize an autonomy-supportive style; and to provide students rationale for engaging in important and compulsory even though non-interesting activities. These authors also assert that teachers can easily learn these and other instructional strategies that facilitate learner autonomy.

Furthermore, the results of this study also underscore the role of the expectancy-value model on metacognitive engagement and performance in academic contexts. Fredricks *et al.* (2010) assert that the teachers are more likely to create classrooms that increase interest and importance when they model enthusiasm, show a caring attitude, adapt instruction to students' needs and interests, press students for active learning and understanding, and provide clear and frequent feedback. Likewise, Wigfield *et al*. (2009) highlight some effective teaching practices that improve expectancy and value of a task: to establish good relationships in class with students in a relaxed atmosphere; reduce to a minimum note-taking, and maximize practical work; make their instructions and explanations clear; provide an adequate level of challenge to avoid boredom and disaffection; explain to students the importance of the contents for their future lives; and use ICT to enhance and enrich teaching practices.

According Schraw *et al*. (2006), Sinatra and Taasoobshirazi (2011) and Ben-David and Orion (2013), science teachers should reduce the amount of instructional time devoted to conceptual understanding, and increase the amount of time devoted to procedural and metacognitive understanding. Analogously, Thomas and Anderson (2014) assert that students should be seen as self-reflective learners, and should engage in metacognitive reflection regarding both what it means to learn science and their learning processes. These and other authors (see also Zohar and Barzilai, 2013) identified some approaches for infusing metacognition in classroom interactions within and across all science subjects: repeated explicit training and practice for activating and applying metacognition in multiple problems and contexts; explanations and discussions in which teachers talk with their students about metacognitive thinking and learning; and modelling in which the teacher demonstrates how she/he activates and applies metacognitive strategies in the course of learning and problem-solving.

Likewise, Michalsky (2012), Ben-David and Orion (2013), and Zohar and Barzilai (2013) recognize that metacognition is almost invisible to science teachers, which highlights the need for in- and pre-service teacher training in the knowledge and practice of metacognitive instruction as the only means of encouraging teachers to use self-regulatory strategies in the classroom.

Limitations and future research

The present study assessed two main components of autonomy support i.e., choice and relevance. Further studies are required to evaluate other aspects, such as respect and control (see Belmont *et al.*, 1992; Soenens *et al*., 2012; Reeve *et al*., 2014), in order to examine their relations with motivational, metacognitive, and performance variables. Furthermore, autonomy support was evaluated through students' perception. Future studies could evaluate autonomy support through the teachers' estimation of their own behaviour in class (see Soenens *et al.*, 2012; Reeve *et al.*, 2014), or by observation of classroom interactions by trained experts (see Reeve and Gang, 2006; Jang *et al*., 2010). Moreover, according to Jang *et al*. (2010), other constructs should also be considered such as the "teacher-provided structure" defined as the amount and clarity of information that teachers offer to students about expectations and ways of effectively achieving desired educational outcomes.

This study has not assessed one of the components of task-value i.e., "perceived cost". Though it is one of the least evaluated components, recent research has underscored the relevance of this variable for learning mathematics (Conley, 2012; Trautwein *et al*., 2012), and chemistry at university (Perez *et al*., 2014). Thus, future studies may examine how this variable interacts with engagement and emotions in learning chemistry.

In this study, the Regulation of Cognition scale (Taasoobshirazi and Farley, 2013) was applied to assess metacognitive problem-solving strategies. In addition, these findings could be complemented with the analysis of other relevant metacognitive variables in chemistry education, such as performance self-evaluation or confidence judgments (Mathabathe and Potgieter, 2014), metacognitive learning strategies (Cook *et al*., 2013), and metacognitive experiences in classroom (Thomas and McRobbie, 2013). Moreover, in the present study only one of the components of metacognition was analysed i.e., regulation of cognition.

Nevertheless, future studies may consider the analysis of knowledge of cognition due to its considerable contribution to learning in chemistry (see, for example, Cooper *et al*., 2008; Cooper and Sandi-Urena, 2009; Taasoobshirazi and Farley, 2013; Wang and Chen, 2014).

Cognitive variables were not assessed in the present work, though several authors have underscored their decisive role in performance in chemistry (see, among others, Zusho *et al.*, 2003; Taasoobshirazi and Sinatra, 2011; Zeyer *et al.*, 2012). In the future, besides motivation and metacognition, cognitive variables could also be included in SEM models to analyse the impact of each one on predicting engagement and performance in chemistry.

The proposed model of relations fitted the data in a sample of undergraduates from an array of degrees where the introductory subject of chemistry was (in nearly all cases) the only compulsory subject on the syllabus. It remains to be ascertained if the proposed model would be confirmed in a sample of undergraduates on degrees with several chemistry subjects (*e.g.*, Pharmacy, Marine sciences) or degrees where chemistry is a core field of knowledge (*e.g.*, Chemistry or Chemical Engineering). Undergraduates on these degrees have rarely been analyzed in previous studies, and it would be most useful to further our understanding of their motivation to study chemistry and their use of metacognitive strategies when studying, in laboratory activities and in problem-solving process.

The quantitative data obtained in this study can be complemented with qualitative research, such as the work of Sandi-Urena *et al*. (2011 c), Thomas and McRobbie (2013), Thomas and Anderson (2014), or Ferrell and Barbera (2015) studying metacognition, motivation, engagement, problem-solving and performance in chemistry.

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Appendix: Covariance matrix of the observed variables

The off-diagonal indices are the covariances for pairs of indicators; the diagonal indices are the variances for each indicator.

	AuSu1	AuSu2	AuSu3	AuSu4	Expe1	Expe2	Expe3	Expe4	Impo1	Impo2	Util1	Util2
AuSu1	0.782											
AuSu2	0.318	0.797										
AuSu3	0.387	0.372	0.896									
AuSu4	0.290	0.335	0.336	0.909								
Expe1	0.111	0.007	0.068	0.174	1.270							
Expe2	0.670	0.024	0.070	0.130	0.534	1.151						
Expe3	0.067	0.017	0.011	0.131	0.658	0.566	1.082					
Expe4	0.002	0.023	0.013	0.119	0.660	0.636	0.680	1.368				
Impo1	0.165	0.047	0.020	0.087	0.395	0.313	0.329	0.422	1.209			
Impo2	0.150	0.077	0.040	0.089	0.355	0.301	0.276	0.344	0.658	1.162		
Util1	0.153	0.078	0.042	0.134	0.457	.0303	0.349	0.375	0.440	0.453	1.180	
Util2	0.168	0.137	0.065	0.113	0.417	0.243	0.279	0.342	0.458	0.413	0.682	1.143
Inter1	0.110	0.012	0.067	0.148	0.486	0.408	0.345	0.457	0.585	0.529	0.482	0.450
Inter2	0.101	0.023	0.011	0.125	0.509	0.416	0.443	0.482	0.634	0.613	0.486	0.465
Plan1	0.175	0.133	0.052	0.173	2.620	1.950	2.270	3.360	0.376	0.310	0.346	0.294
Plan2	0.112	0.039	0.058	0.113	3.030	1.860	2.320	3.430	0.276	0.284	0.289	0.265
Plan3	0.146	0.130	0.039	0.118	2.980	2.490	2.660	3.430	0.357	0.327	0.298	0.313
Plan4	0.065	0.026	0.027	0.108	2.750	2.080	2.580	3.610	0.378	0.262	0.295	0.332
Plan5	0.117	0.160	0.133	0.145	3.680	2.090	2.380	3.440	0.358	0.364	0.245	0.321
Moni1	0.170	0.134	0.141	0.234	0.597	0.444	0.528	0.557	0.569	0.550	0.529	0.436
Moni2	0.213	0.120	0.164	0.171	0.362	0.318	0.340	0.352	0.533	0.520	0.554	0.501
Moni3	0.143	0.089	0.122	0.228	0.542	0.426	0.461	0.492	0.559	0.508	0.547	0.545
Moni4	0.223	0.083	0.184	0.187	0.600	0.353	0.442	0.491	0.547	0.562	0.542	0.521
Eval1	0.248	0.200	0.176	0.256	0.476	0.377	0.343	0.546	0.567	0.496	0.504	0.530
Eval2	0.200	0.130	0.126	0.181	0.560	0.487	0.451	0.612	0.608	0.560	0.548	0.501
Eval3	0.253	0.207	0.170	0.267	0.588	0.435	0.483	0.693	0.661	0.590	0.631	0.580
Perfor	0.340	0.206	0.202	0.374	0.780	0.631	0.733	0.864	0.956	0.910	0.900	0.899

	Inter1	Inter2	Plan1	Plan2	Plan3	Plan4	Plan5	Moni1	Moni2	Moni3	Moni4	Eval1
Inter1	1.131											
Inter2	0.901	1.478										
Plan1	0.352	0.419	9.500									
Plan2	0.331	0.355	0.338	8.120								
Plan3	0.421	0.445	5.050	3.500	9.510							
Plan4	0.320	0.365	4.170	4.430	3.800	9.040						
Plan5	0.340	0.389	3.680	2.920	3.570	3.060	1.014					
Moni1	0.581	0.641	2.780	2.550	3.040	2.550	3.360	1.408				
Moni2	0.531	0.608	2.230	2.460	2.960	2.850	3.470	0.856	1.483			
Moni3	0.589	0.718	2.780	3.130	2.930	3.050	3.600	0.974	1.021	1.538		
Moni4	0.545	0.692	3.340	3.580	3.630	2.710	3.730	0.862	0.853	0.979	1.502	
Eval1	0.638	0.617	0.214	0.297	0.319	0.306	0.415	0.604	0.611	0.688	0.648	1.482
Eval2	0.627	0.700	0.292	0.277	0.374	0.299	0.355	0.615	0.575	0.662	0.653	0.935
Eval3	0.762	0.758	0.392	0.393	0.419	0.413	0.492	0.716	0.714	0.833	0.847	1.120
Perfor	1.018	1.044	0.714	0.583	0.696	0.622	0.710	1.025	1.100	1.167	1.044	1.043

	Eval2	Eval3	Perfor
Eval2	1.537		
Eval3	1.154	1.811	
Perfor	1.043	1.392	2.804

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