RESEARCH ARTICLE

Disposition towards Critical Thinking, Academic Level, Gender and Problem Solving in Secondary Education

Disposición hacia el pensamiento crítico, nivel académico, género y resolución de problemas en educación secundaria

Disposição ao pensamento crítico, nível acadêmico, gênero e resolução de problemas no ensino médio

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ABSTRACT

The purpose of this study was to investigate the possible influence of disposition towards critical thinking, academic level, and gender (independent variables) on the problem-solving performance of secondary school students (dependent variable). A total of 114 Spanish secondary school students participated, 55 boys and 59 girls, from 3rd and 4th ESO and 9th, 10th and 11th grade (High School) respectively. All of them have been administered a questionnaire on disposition towards critical thinking and a problem-solving test (a problem of the PISA tests). From the Pearson product-moment correlation matrix between variables and the *backward stepwise* regression analysis, the following conclusions have been derived: 1) the disposition towards critical thinking (i.e., the potential use of critical thinking) and gender seem to have an insignificant weight on problem-solving performance; and 2) academic level shows a very prominent contribution to problem-solving performance.

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RESUMO

O objetivo deste estudo foi investigar a possível influência da disposição para o pensamento crítico, nível acadêmico e gênero (variáveis independentes) no desempenho na resolução de problemas de alunos do ensino médio (variável dependente). Participaram 114 alunos espanhóis do ensino secundário, 55 garotos e 59 garotas, do 3º e 4º do ESO e do 1º de ensino médio (9º, 10º e 11º ano, respectivamente). Todos eles receberam um questionário sobre a disposição para o pensamento crítico e um teste de resolução de problemas (um problema nos testes PISA). A partir da matriz de correlação produto- momento de Pearson entre as variáveis e a análise de regressão backward stepwise realizada, as seguintes conclusões foram derivadas: 1) a disposição para o pensamento crítico (isto é, o uso potencial do pensamento crítico) e o gênero parecem têm peso insignificante no desempenho de resolução de problemas; e 2) o nível acadêmico mostra uma contribuição muito importante para o desempenho na resolução de problemas.

Introduction

According to Fisher (2011) critical thinking can be defined as the set of processes that allow a well-founded decision to be made on conflicting issues or problems, although it seems that it is difficult to establish its nature or if its characteristics have a general character (Phillips & Bond, 2004). Everything indicates that critical thinking is related to the skills that are present in problem solving, decision making, inferences, divergent thinking, evaluative thinking, reasoning processes or knowledge transfer (Carvalho *et al.*, 2015). Kuhn (1999) was one of the first to suggest a model of critical thinking development. In this model it is defended that critical thinking is based on three cognitive pillars: a metacognitive one, a metastrategic one and a epistemological one. More recent research places critical thinking within one of the self-regulatory components of learning, specifically within cognitive strategies (Phan, 2010; Schraw, Crippen, & Hartley, 2006).

Thinking critically is a basic competence that all citizens should develop in compulsory education in order to actively participate in society (Ten Dam & Volman, 2004). Thus, for example, creativity is closely linked to critical thinking skills (Tsai, 2019). However, not all students can adequately develop this competence, nor do all teachers use methodologies that make it possible to develop critical thinking in their students (Pithers & Soden, 2000). Ku and Ho (2010) examined the role of metacognitive skills in the development of critical thinking, and found that the involvement of students in activities involving the application of assessment and planning strategies leads to an improvement in critical thinking. Magno (2010) analyzed the effect of metacognitive skills on critical thinking using a model of structural equations, and concluded that these skills intervene significantly in critical thinking. On the other hand, metacognitive skills have been shown to progress as secondary education progresses (Van der Stel, Veenman, Deelen, & Haenen, 2010; Veenman, & Spaans, 2005). Consequently, critical thinking can be expected to improve throughout secondary education.

Ennis (1987) already pointed out in the 80s that critical thinking strategies included necessary problem-solving skills. Subsequently, Facione (1990) carried out a study to identify critical thinking in university students and highlighted that this is linked to activities of high cognitive level, decision making and problem solving. Pushkin (2007) offered an explanation of how critical thinking helps in problem solving based on two types of knowledge: strategy knowledge and situational awareness. Friede, Irani, Rhoades, Fuhrman and Gallo (2008) determined critical thinking skills (through a content analysis of a *think-aloud* protocol) and found that these contribute little, but significantly, to problem solving. These authors state that more research is needed to clarify how and where critical thinking affects problem solving. The work of Özyurt (2015) examined the research conducted on the incidence of critical thinking in problem solving, which, as the author indicates, is very few and focused on two groups: faculty (active or in training) and nursing students.

As Butler (2012) points out, critical thinking is a complex construct and, as such, difficult to evaluate. A distinction is often made between critical thinking skills and a willingness to think critically. Facione's (1990) study found that critical thinking is composed of critical thinking skills and a willingness toward critical thinking. Later, Norris (1994) concluded that the disposition toward critical thinking was necessary for the appropriate use of critical thinking skills. However, Halpern (2003) considers that both critical thinking skills and willingness to use them are involved in the same reasoning process. In fact, Rikectts and Rudd (2005) found a positive and significant correlation between both variables.

The results of the study by Tümkaya, Aybek and Aldaş (2009) show that having a better disposition towards critical thinking is associated with better problem-solving skills. Özyurt (2015) also found a significant correlation between both variables, but at a low level. In both cases the participants were university students. Kawashima and Shiomi concluded that gender does not produce significant differences in high school students' willingness toward critical thinking (Kawashima & Shiomi, 2007).

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Improving problem-solving performance continues to be a central goal of science and mathematics teachers, as well as researchers in science and mathematics didactics. To achieve this goal, Lee, Tang, Goh and Chia (2001) proposed that problem-solving skills had to be developed in specific activities in the classroom, and that it was necessary to know and address the difficulties of the students during the resolution. All this cannot be achieved if the cognitive processes and knowledge that are put into play during resolution are unknown (Solaz-Portolés & Sanjosé, 2008). It has been proven in several studies that the performance in problem solving improves as students move towards secondary education, in accordance with the improvement of knowledge and strategies that is generated (Alabau, Solaz-Portolés, & Sanjosé, 2020; García-Gallego, Sanjosé, and Solaz-Portolés, 2015; Mugarra-Soldevila, Solaz-Portolés, Caurín-Alonso, 2014). On the other hand, the meta-analyses carried out by Hyde, Lindberg, Linn, Ellis and Williams (2008) and Lindberg, Hyde, Petersen and Linn (2010), confirm that girls and boys perform very similarly in problem-solving tests. However, in the literature review carried out by Zhu (2007) there are investigations in which genre produces significant differences in problem solving, specifically men seem to outnumber women. In fact, Gallagher *et al.* (2000), found that boys outperform girls in solving complex problems.

As we have seen, critical thinking is actively involved in problem-solving processes. In addition, resolution processes can be affected by both gender and the academic level of the students who carry them out. On the other hand, the difficulty of assessing critical thinking has been pointed out, which does not occur with the disposition towards critical thinking, which is closely associated with critical thinking skills. Given the scarcity of jobs in secondary education where the relationship between performance in problem solving and the disposition towards critical thinking are analyzed, the problem that we want to investigate in this study is the possible influence of the disposition towards critical thinking, the level of academic training and gender (independent variables) on the problem-solving performance of secondary school students (dependent variable). Specifically, the objectives of the study were: a) To evaluate the relationship between each of the independent variables and the dependent variable; b) To examine the relative contribution of the three independent variables to the variability of the dependent variable; and c) To determine the independent variable that best predicts problem-solving performance.

Methodology

Participants

31 students from 3rd year of Compulsory Secondary Education -ESO- (9th grade, 14-15 years old), 37 from 10th grade (15-16 years old), and 46 from high school (11th grade, 16-17 years old) participated. Of the total of 114 students, 55 were boys and 59 girls. This is a convenience sample of students from a public secondary school in Valencia (Spain). These subjects do not present, *a priori*, special characteristics that differentiate them from other groups of the respective courses. However, the results cannot yet be reliably extrapolated to the entire student population of these courses.

Instruments

The questionnaire *Critical Thinking Motivation Scales* (Valenzuela, Nieto, & Saiz, 2011) has been used to measure the disposition towards critical thinking. It is an instrument to measure the degree of motivation that people can have to think critically. It has a total of 19 items that are grouped into 5 blocks or factors, all of them referring to critical thinking: expectations, scope, utility, cost and interest. Thus, some propositions included in the items refer to what is expected of critical thinking (expectations), others to the value that is given to it (value). There are also propositions about the importance of using this way of thinking (utility), about the harms you are willing to accept (cost) and the benefit that is expected of it (interest). It was translated into Spanish and revised and adapted (after being read by three high school students) by two university professors and a high school teacher. Here is an example of each factor:

- Expectations: "I can learn how to reason correctly better than most of my peers"
- Value: "For me, it's important to use my intellectual skills correctly"

- Utility: "Critical thinking is useful on a day-to-day basis"
- Interest: "I like to reason in a rigorous way"
- Cost: "I am willing to sacrifice much of my time and effort in order to improve my way of reasoning"

The questionnaire uses a Likert scale with six levels of response, ranging from completely disagree (score 1), to completely agree (score 6). The order of the items in the questionnaire was randomized.

A problem-solving test was also administered, which includes a problem from the PISA tests of 2003 (Inecse, 2005), with two sections. This problem can be seen in Annex 1. This test was intended to measure each student's problem-solving performance. For its evaluation, the evaluation rubric that is attached to the problems in Inecse (2005) was used. The first section has a maximum score of 1 point, and the second 3 points. Therefore, the score of the problem-solving test ranges from 0 to 4 points.

The questionnaire on readiness towards critical thinking was administered during the last 25 minutes of a normal class session. Students were asked to read carefully all the items in the questionnaire and to answer with the utmost sincerity. The problem-solving test was administered in another normal class session and took between 15 and 20 minutes.

The qualification of the problem-solving test was made by two authors of this study by applying the rubric of the PISA tests (Cohen's Kappa Coefficient 0.93). Both the grade of this test and that obtained in the questionnaire were transferred to an Excel spreadsheet and then the statistical analyses were carried out.

Results

First, the Cronbach's alpha coefficient of the questionnaire on readiness towards critical thinking has been calculated, which has provided a value of 0.82, which indicates a high level of reliability. The arithmetic means and the standard deviation of the scores obtained in the problem-solving test and in the questionnaire (sum of the scores in all the items of the same) according to the academic level and gender, are shown in Table 1. The overall average disposition towards critical thinking is 86.17 points (maximum score in the questionnaire 114 points), a medium-high score. Table 1 shows that the averages in this variable cover a range from 83.33 to 89.21 points. For its part, the overall average of the problem-solving test is 2.10 points (maximum score in the test 4 points), an average score. The means in this variable fluctuate between 0.81 and 3.35 points.

Table 1. Descriptive statistics of the variables in the study

Variable	Level academic	Gender	Mean	SD
Provision Critical Thinking (Score maximum 114)	3rd ESO	Boy	83.33	13.39
		Girl	88.31	12.99
	4th ESO	Boy	84.09	9.52
		Girl	86.64	11.78
	1st High Sch	Boy	83.88	17.04
		Girl	89.21	10.24
Problem Solving (Score max 4)	3rd ESO	Boy	1.27	1.10
		Girl	0.81	1.05
	4º ESO	Boy	1.70	1.15
		Girl	2.07	0.92
	1st High Sch	Boy	3.35	0.86
		Girl	2.83	1.00

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Table 2 presents Pearson's matrix of product-moment correlations of the variables involved in the study, including academic level (value 0 has been taken for 3rd of ESO, value 1 for 4th of ESO, and value 2 for 1st of High school) and gender (considering value 0 for boys and value 1 for girls). It can be observed that problem solving and disposition towards critical thinking present a positive, but small and not significant correlation (r = 0.15, p>.05), as well as the disposition towards critical thinking and gender (r = 0.18, p>.05). The correlation between problem solving and academic level is very high (r = 0.62, p<.00001). There is no correlation between problem solving and gender (r= 0.00), nor between disposition towards critical thinking and academic level (r= 0.05).

Table 2. Pearson product-moment correlations between variables

	Prob. solving	P.C.Provision	Academic level	Gender
Prob. solving	1	0.15	0.62*	0.00
P.C. Provision		1	0.05	0.18
Academic level			1	0.11

*p<0.00001 Source: own elaboration

In order to study whether the score obtained in the problem-solving test can be predicted from the other variables put into play in this research, a multiple regression analysis was carried out. In this analysis, the score on the problem-solving test was taken as a dependent variable, or criterion, and as independent variables, or predictors, the score of disposition towards critical thinking, academic level and gender. Regression analysis was performed step by step with the backward method (*backward stepwise*). Table 3 summarizes the regression contrast (analysis of variance) to verify whether the independent variables are linearly related (they influence jointly and linearly) with the dependent variable, that is, they provide information in the explanation of the dependent variable. The F significance level is less than 0.00001, therefore the regression model is statistically significant to explain the dependent variable or criterion. As for the goodness of fit, the square of the multiple correlation coefficient (R_2) is 0.394, which indicates that the three independent variables or predictors account for 39.4% of the variance of the score of the criterion variable (beliefs about science). The remaining 60.6% must be explained by other variables not contemplated in this experiment and by the variance of the error.

Table 3. Analysis of variance of the multiple regression model

Source	Degrees of Freedom	Sum of quadratic squares	Means	F Value	P	R_2
Model	1	76.08	76.08	71.10	<0.00001	0.394
Error	112	119.86	1.07			
Total	113	195.94	1.73			

Source: Own elaboration

Table 4 shows the regression coefficients of the three independent variables in the regression equation. Note that there are two predictors whose level of significance is not statistically significant. The inflation factors of variance are also offered, which allow estimating the level of multicollinearity among the predictors of the regression model. All are very slightly greater than 1, indicating a very low degree of collinearity.

Table 4. Regression analysis coefficients for predicting problem-solving performance

	Coef. non-standardized regression	Typical Error	T-test	p	Facto inflation variance
Intersection	-0.15	0.69	-0.22	0.827	
Provision Critical P.	0.01	0.01	1.78	0.078	1.0
Academic level	1.01	0.12	8.50	<0.00001	1.0
Gender	-0.24	0.20	-1.22	0.225	1.0

Source: Own elaboration

As mentioned the regression analysis performed was step by step backwards (*backward stepwise*). In this type of regression, the predictor variables are eliminated at each step when their significance exceeds a certain limit (in this case, $p>.05$). In the first step, the gender variable was eliminated and in the second step the variable disposition towards critical thinking. In both cases no appreciable change was observed in R_2(in the first elimination it goes from 0.394 to 0.391, and in the second to 0.388), that is, it is corroborated that these variables do not contribute significantly to the explanation of the variance of the problem-solving test score. Table 5 shows the results in the last step of the analysis.

Table 5. Results of the backward *stepwise* regression analysis for the prediction of the level of beliefs about science in the last step

	Coef. non-standardized regression	Typical Error	T-test	p
Intersection	0.96	0.17	5.76	<.00001
Academic level	1.01	0.12	8.43	<.00001

Therefore, the regression equation that relates the score of the problem-solving test (PRP), or performance in problem solving, and the only significant predictor, academic level (NA), is PRP = 0.96 +1.01 NA.

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Discussion

The high scores obtained in the questionnaire of disposition towards critical thinking should be highlighted, which, as can be seen in Table 1, are located in a medium-high score range. These results contrast with those obtained by Zoller *et al*. (2000) with a very different instrument (long, 75 items), where the level given by Italian and Israeli students of the last year of secondary school (17-18 years) was medium (about 56 points, on a maximum score scale of 100). It seems that students who participated believe they have a great disposition towards critical thinking. The scores on the problem-solving test, ranging from a low level in 3rd ESO (9th grade) to a high level in 1st year of High school (11th grade), are similar to those of another job where the same problem was used (Pellicer, Solaz-Portolés, & Sanjosé, 2019).

As for the gender variable, the values of the Pearson correlation coefficients and the linear regression analysis performed indicate that its influence on problem-solving performance is negligible. That is, in secondary education boys and girls do not present significant differences in performance in problem solving, as also happened in the study of Doktor and Heller (2008). These results are also consistent with those obtained by Alabau, Solaz-Portolés and Sanjosé (2020) and Hyde and Mertz (2009). These last two authors go so far as to affirm that girls have reached parity with boys in problem solving. However, Hyde et al. (2008) emphasize that boys do significantly better complicated problems at the beginning of secondary education and that this circumstance could explain the low presence of women in certain degrees in the STEM area.

Pearson's table of product-moment correlations (Table 2) shows us that academic level has a very high correlation coefficient with problem-solving performance, and very low with the disposition towards critical thinking. In regression analysis, its relative contribution to the prediction of performance in problem solving is the most important of all variables and, in fact, the only significant one. This result is consistent with the results of different researches where the academic level appears associated with the improvement in the resolution of students' problems (Alabau, Solaz-Portolés, & Sanjosé, 2020; García-Gallego, Sanjosé, and Solaz-Portolés, 2015; Mugarra-Soldevila, Solaz-Portolés, Caurín-Alonso, 2014). On the other hand, the almost zero correlation between academic level and disposition towards critical thinking, or, in other words, that the increase in academic level does not alter the disposition towards critical thinking, agrees with the results obtained by Özyurt (2015) with university students. However, it contradicts studies that confirm the improvement in metacognitive skills as one advances in secondary education (Van der Stel, Veenman, Deelen, & Haenen, 2010; Veenman & Spaans, 2005).

Finally, the correlation coefficient between readiness toward critical thinking and problem-solving performance has turned out to be positive, low, and not significant. In regression analysis its relative contribution to the prediction of performance in problem solving has not been significant, and its contribution to the explanation of the variance of the criterion variable has turned out to be practically null (exactly 0.3%). This result differs from those found by Özyurt (2015) and Tümkaya et al. (2009), who found a significant association between disposition towards critical thinking and problem-solving skills. These differences could be justified both by the type of participants (high school students vs. college students), and by the type of problem-solving test (PISA test problem vs. questionnaire where generic problem-solving skills are evaluated – that is, students have not solved a problem, but have self-assessed their problem-solving skills).

Conclusions

It is necessary to underline, first, the limitations of this work. The main limitation is in the nature and size of the sample. The selected sample is small and not the result of random sampling. In addition, only three levels of secondary education have participated in the variable academic level. Other limitations may have their origin in the instruments that have been used. Thus, all the conclusions set out below are only valid, in the strict sense, for the participating students and with the instruments used.

It seems that, of all the variables put into play, the academic level or conjunction of academic training and the evolutionary development of students, which implies an improvement in conceptual knowledge and knowledge and strategies related to problem solving, as well as the increase of other cognitive variables (metacognitive skills, working memory capacity, etc.) and motivational (self-efficacy, positive emotions, etc.), it is the one that has the most weight in the resolution of academic problems. Gender has shown no effect on problem-solving performance, and the disposition toward critical thinking has only been noted for its coefficient of positive correlation with problem-solving performance, low and non-significant. In this way, it has been suggested that it can contribute to problem solving.

Thus, and even though the literature emphasizes the interrelationship between problem solving and critical thinking, on this occasion no such link has been evidenced. More studies are needed on this question, as well as simple and reliable tools that allow us to approach the critical thinking of students. Likewise, the type of problems students solve is also decisive. The usual academic problems (non-real problems, where all the necessary data are provided, the resolution procedure is known, and the objective is clearly defined) do not leave much room, strictly speaking, for critical thinking. It should be investigated whether in real and more open problems critical thinking has a more relevant role.

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