ACTA DIDACTICA NAPOCENSIA

Volume 4, Number 1, 2011

A STUDY OF THE PROBLEM SOLVING ACTIVITY IN HIGH SCHOOL STUDENTS: STRATEGIES AND SELF-REGULATED LEARNING

Alexandru Brad

Abstract: This study was conducted with the purpose of analyzing high school students' approach to problem solving activities, namely the metacognitive abilities and the strategies they employ. The results show that although students apply basic strategies well, they use a trial-and-error approach, they give-up when faced with difficulties and have deficiencies in metacognitive abilities, which are signals that must be taken into account. The conclusions suggest that greater attention should be given to the students' needs, putting more emphasis on reasoning and understanding, so that students can improve their self-regulated learning.

Key words: problem solving, self-regulated learning, strategies

1. Introduction

Problem solving is one of the most widely used educational activities in Romanian high schools, especially those that are centered on Mathematics and Computer Science. Consequently it is of great interest to identify the ways in which students approach this type of task. This is what constitutes the rationale of this pilot study, conducted locally, in one high school, as an attempt to analyze the strategies which students employ in the solving problem process and their motivation and metacognitive abilities, with the final purpose of discovering critical issues and making suggestions for improvement.

Before going further, the meaning of the term "problem" must be established. The Oxford Dictionary defines the word as a "matter or situation regarded as unwelcome or harmful and needing to be dealt with and overcome" or "Physics & Mathematics: an inquiry starting from given conditions to investigate or demonstrate a fact, result, or law" [1]. In Romanian, the word used is "problema", and is defined by the Explicative Dictionary of the Romanian Language as "a matter which contains unclear, debatable aspects", "an important matter which represents a major task that must be dealt with immediately", "Mathematics: a matter that, given a hypothesis, must be solved through computation and reasoning, in order to obtain certain data", or "something that is hard to understand, solve, or explain" [2]. It can be seen that the English and the Romanian terms are roughly equivalent, with the mention that the Romanian mathematical definition is slightly more restrictive than its counterpart. In Romanian schools, the main understanding of the term is the mathematical one, which is why most of the people involved in the educational process, be they teachers or students, equate it with the "text-book problem", depriving it of any other meaning in the educational context. However, there are other views that take a less restrictive approach, such as that of J. Hayes who states that: "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem." [3] This last definition is the one adopted in this study, as it is considered the most appropriate for what in-school problem solving must entail. Nevertheless, the results are highly dependent on the participating students' own definition hence they should be regarded from the more restrictive perspective as well, considering the fact that it may very well be more accurate.

Disregarding the frequency of the problem solving activity in high school, its importance remains intact given that it is highly practical and grounded in reality compared to most other activities in use.

Received 1 March 2011, accepted 25 March 2011, published 30 March 2011.

It could be stated that the way students handle problems in school will be reflected in their approach to the complexities of adult life, therefore the strategies they employ and the way they regulate their learning process are matters of great interest. This study takes a snapshot of these elements and performs a detailed analysis, taking into account the students' gender, age, grade, GPA, or parents' education, with the purpose of discovering critical situations and making suggestions for improvement.

The study gives special attention to the theory of self-regulated learning, which is an interaction of several factors (personal, behavioral, or contextual) impacting the academic achievements of students [4]. Other studies have shown that elements like self-concept and especially self-efficacy have a significant influence on how students approach the tasks they are presented with and face up to the challenges they encounter[5][6][7][8]. It is also generally accepted that guiding students towards acquiring or improving their metacognitive abilities should be a major concern of educators [9]. Thus, an insight the metacognitive strategies students utilize can be of great value, especially if the conclusions could help design interventions for improvement.

2. Method

Sample

Since this is a pilot study and its purpose is to analyze problem solving activities locally, the sample size is rather small and it was selected entirely from a single high school, which gathers the elite in an area with a population of 150,000. Two classes and two subgroups (a class is divided into two groups) were chosen, all of which are of Mathematics and Computer Science specialty, representing grades 9, 10, and 12, and totaling 80 students. The socio-economic backgrounds of the students as well as their parents' educations were heterogeneous, ranging from unemployed or minimum-wage earning parents with only lower secondary education, to high-earning university professors and doctors.

Survey content

The survey that was handed to the students contained two sections:

- general information (age, grade, parents' occupation, GPA);
- items regarding the actual problem solving activities and metacognitive abilities;

There are 11 items concerning problem solving activities, partitioned in two groups (in the actual survey handed to the students they were arranged so that the flow would be most natural, rather than according to the group they belong to), as shown below:

- Problem solving strategies
    - I recall problem types studied in the past in order to categorize the problem to be solved.
    - Before solving a problem I make a mental plan of the process.
    - I read the problem statement several times.
    - I use various problem solving strategies according to the problem.
    - I use problem solving methods and strategies without thinking much about what I am using, how and why.
    - I solve the problem by trial and error.
    - I start solving a problem by applying formulae which seem appropriate.
- Motivation and metacognitive abilities
    - If I encounter difficulties while solving a problem I give up.
    - I think about how efficient my learning process is when solving a problem.
    - If a problem seems too difficult, I give up.
    - Upon solving a problem I ask myself what have I learned in the process.

For each item the student was asked to choose a number from 1 to 5 corresponding to the degree of agreement to the corresponding assertion.

Procedure

The surveys were handed out to the students during classes and they were given 10 to 15 minutes to complete them. Before commencing, they were instructed on the filling procedure, special attention being given to the significance of the numbers from 1 to 5 in order to avoid entirely erroneous (backwards) data.

Due to students' missing class for various reasons and a few invalidated surveys, the size of the sample was reduced to 72.

3. Results

Table 1 shows the means and standard deviations of responses for each item. Most of them are normally distributed, having a mean in the vicinity of 3 and a standard deviation very close to 1, but there are a few exceptions, which show that students generally *read the problem statement several times* (mean = 3.606), *recall problem types studied in the past in order to categorize the problem at hand* (mean = 3.592), and *start solving a problem by applying the formulae which seem most appropriate* (mean = 3.729).

Table 1. *Averages and standard deviations of responses*

Item	Mean	Std dev
I recall problem types studied in the past in order to categorize the problem to be solved	3.592	1.077
Before solving a problem I make a mental plan of the process	3.346	1.170
I read the problem statement several times	3.606	1.224
I use various problem solving strategies according to the problem.	3.400	1.172
I use problem solving methods and strategies without thinking much about what I am using, how and why	2.928	1.310
I solve the problem by trial and error	3.214	1.261
I start solving a problem by applying formulas which seem appropriate	3.729	1.048
If I encounter difficulties while solving a problem I give up	2.671	1.380
I think about how efficient my learning process is when solving a problem	2.914	0.989
If a problem seems too difficult, I give up	2.859	1.302
Upon solving a problem I ask myself what have I learned in the process	2.667	1.159

The distributions of answers for each item are shown in Figures 1 and 2 grouped according to the corresponding domain (either strategy or motivation and metacognitive abilities). Most of the responses lie in the middle (2, 3 or 4), with only a few items containing a significant proportion of extreme values. Apart from the items that were mentioned above for having a greater than average mean, it can be noticed that 28% of students *give up when they encounter difficulties* (answered 4 or 5), 30% *do so from the beginning if the problem seems too hard* (answered 4 or 5), and 45% *do not ask themselves about what they have learned upon solving a problem* (answered 4 or 5).

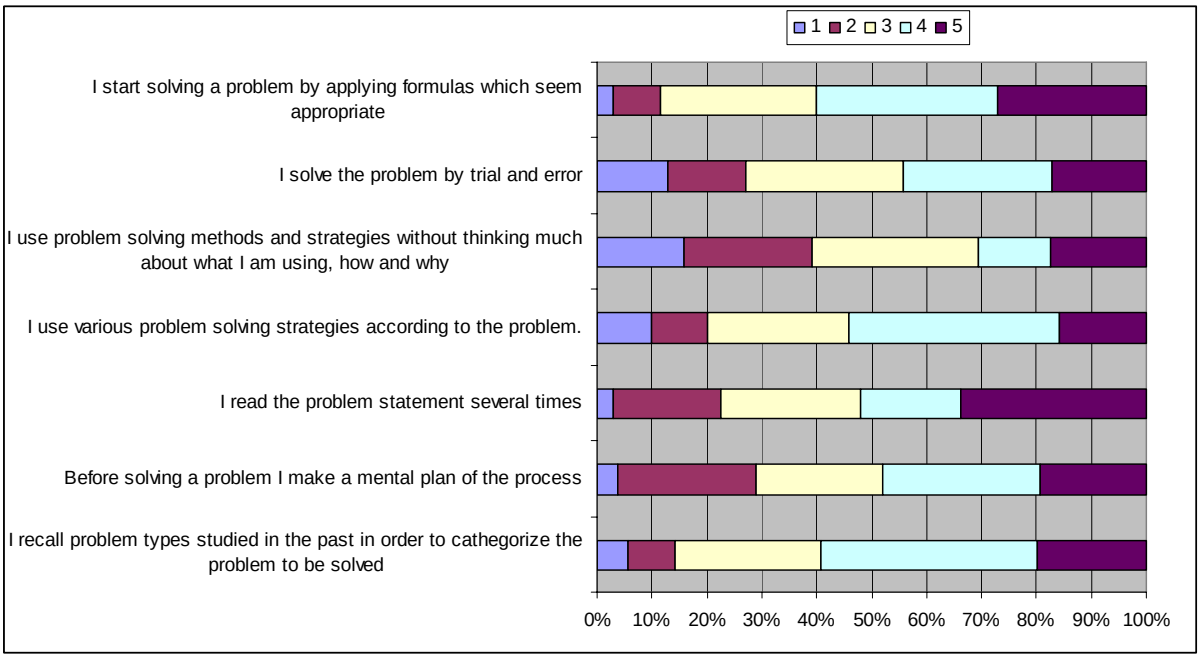

Figure 1. *Strategy items response distribution*

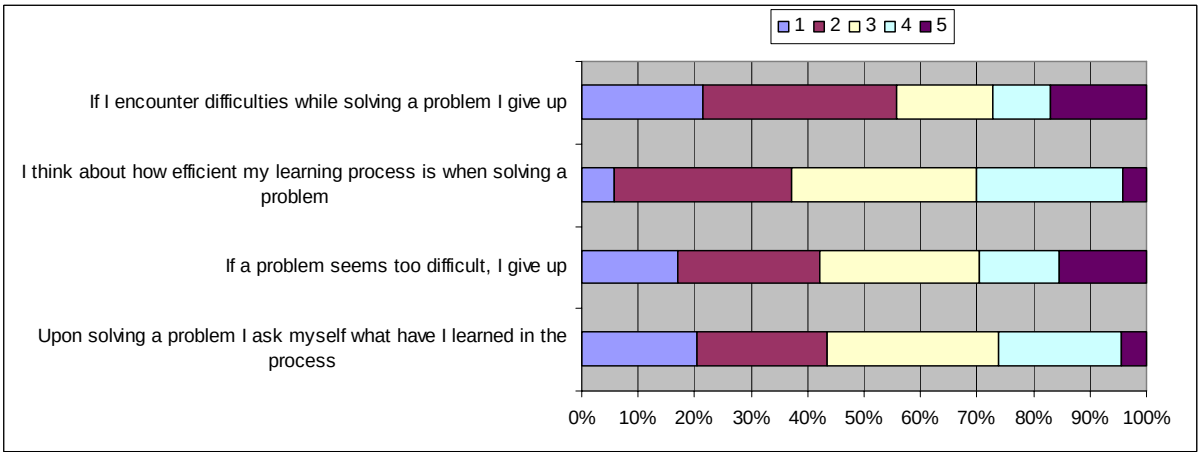

Figure 2. *Motivation and metacognitive abilities items response distribution*

Some of the tables and figures presented are rather large and writing the assertion for each item is not feasible, therefore each item will be encoded by "Q" followed by a number. An index showing the corresponding item for each code is given in Table 2.

The response distribution was also analyzed with respect to the gender of the students and the results can be seen in Figures 3 and 4. Although in general the results were similar, there are some items where differences are apparent. Girls tend to *read the problem statement several times* more often than boys do (42% of girls answered 5, compared to 24% of boys), and, on the other hand, boys surpass girls in *using various problem solving strategies, depending on the problem at hand* (26% answered 5, compared to 9%).

Table 2. *Item index*

Item code	Item
Q1	I recall problem types studied in the past in order to cathegorize the problem to be solved
Q2	Before solving a problem I make a mental plan of the process
Q3	I read the problem statement several times
Q4	I use various problem solving strategies according to the problem.
Q5	I use problem solving methods and strategies without thinking much about what I am using, how and why
Q6	I solve the problem by trial and error
Q7	I start solving a problem by applying formulas which seem appropriate
Q8	If I encounter difficulties while solving a problem I give up
Q9	I think about how efficient my learning process is when solving a problem
Q10	If a problem seems too difficult, I give up
Q11	Upon solving a problem I ask myself what have I learned in the process

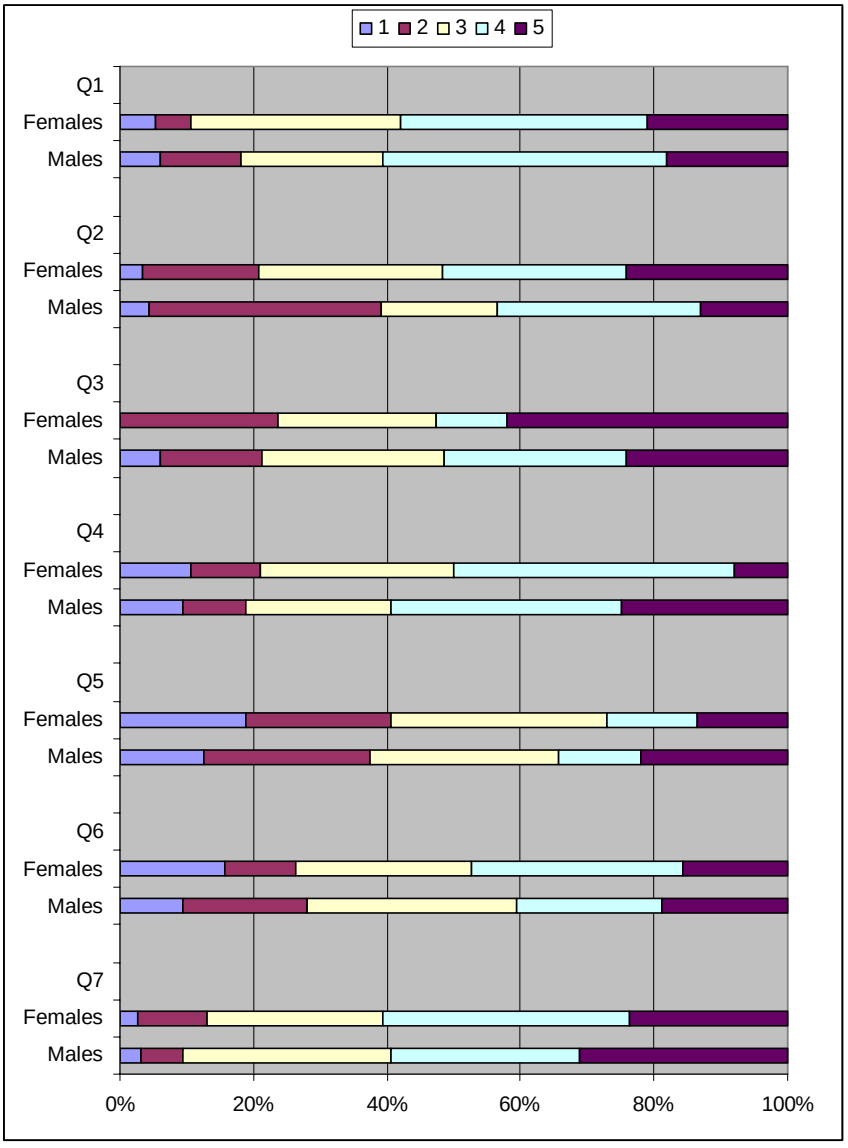

Figure 3. *Strategy items response distribution by gender*

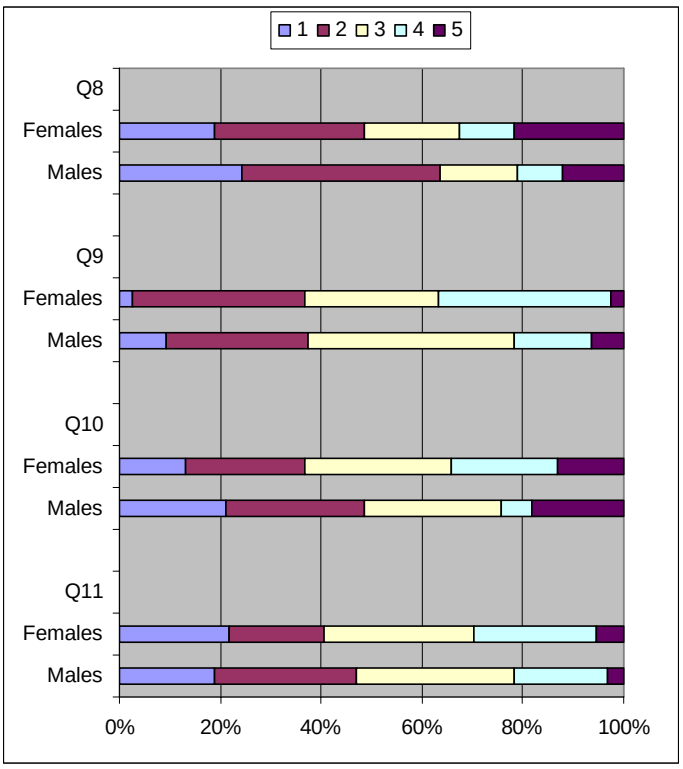

Figure 4. *Motivation and metacognitive abilities items response distribution by gender*

Table 3 shows the correlation to gender, age, grade, parents' education (an index was computed based on their occupation), Math GPA, and overall Science GPA for each item. In order to be considered significant the correlation must be greater (in absolute value) than 0.3. The only other significant correlation suggests that students with a low Math GPA tend to *give up when they encounter difficulties* (correlation of -0.399).

Table 3. *Item response correlation to other factors*

Item	Gender	Age	Grade	Parents' education	Math GPA	Overall Science GPA
Q1	-0.040	-0.039	-0.075	-0.096	-0.061	-0.103
Q2	-0.166	0.190	0.149	-0.066	0.285	0.233
Q3	-0.093	-0.228	-0.206	0.113	-0.175	-0.170
Q4	0.128	0.079	0.113	0.229	-0.065	0.021
Q5	0.097	-0.014	0.010	0.079	-0.100	0.159
Q6	0.003	-0.122	-0.043	0.083	-0.113	-0.113
Q7	0.046	-0.142	-0.133	-0.268	-0.294	-0.322
Q8	-0.149	-0.022	0.020	-0.175	-0.399	-0.213
Q9	-0.095	0.053	0.048	0.031	-0.058	-0.037
Q10	-0.095	0.027	0.023	-0.169	-0.215	-0.237
Q11	-0.059	0.030	0.081	-0.226	-0.155	-0.138

A correlation between different items was also computed and is displayed in Table 4. Significant correlations were identified between different items relating to problem solving strategies, showing that students who *start solving a problem by applying formulae that seem suitable* also *attempt to find*

the solution by trial and error (correlation 0.461), and students who *recall problem types studied in the past in order to categorize the problem to be solved* also *make a mental plan before solving the problem* (correlation 0.383) and/or *start solving a problem by applying formulae which seem appropriate* (correlation 0.312). Also, in the motivation and metacognitive abilities item group, a correlation of 0.446 shows that that students who *give up upon encountering difficulties* also *give up when a problem seems hard*. Apart from the aforementioned intra-group correlations there are a few inter-group correlations as well. Students who *ask themselves what they have learned from solving a problem* also *read the problem statement several times* (correlation 0.365) and/or *start solving the problem by applying the most suitable formulae* (correlation 0.308).

Table 4. *Inter-item correlations*

Item	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Q1	1.000	0.383	0.266	0.162	0.135	0.011	0.312	-0.087	-0.022	0.152	0.233
Q2	0.383	1.000	0.059	-0.022	0.150	-0.219	-0.207	-0.037	-0.004	-0.109	-0.019
Q3	0.266	0.059	1.000	0.179	0.199	0.233	0.139	0.056	0.174	0.278	0.365
Q4	0.162	-0.022	0.179	1.000	0.068	0.202	0.162	-0.165	0.242	-0.113	0.114
Q5	0.135	0.150	0.199	0.068	1.000	0.206	0.124	0.106	0.052	0.002	0.100
Q6	0.011	-0.219	0.233	0.202	0.206	1.000	0.461	0.001	0.188	-0.111	0.166
Q7	0.312	-0.207	0.139	0.162	0.124	0.461	1.000	0.047	0.052	0.148	0.308
Q8	-0.087	-0.037	0.056	-0.165	0.106	0.001	0.047	1.000	0.031	0.446	0.101
Q9	-0.022	-0.004	0.174	0.242	0.052	0.188	0.052	0.031	1.000	0.106	0.271
Q10	0.152	-0.109	0.278	-0.113	0.002	-0.111	0.148	0.446	0.106	1.000	0.136
Q11	0.233	-0.019	0.365	0.114	0.100	0.166	0.308	0.101	0.271	0.136	1.000

4. Discussion

The two main goals of the study were to evaluate the strategies which students employ in the process of problem solving and their motivation and metacognitive abilities.

The results from the strategy section show that most students apply basic strategies, like recalling similar problems, reading the problem statement several times, and even applying different methods according to the particularities of the problem at hand. The high number of intra-group correlations suggests that most students adhere to a bundle of these strategies, developing a personal style, which is of course a positive aspect. However, a significant proportion of students adhere to unproductive strategies based on developing automatisms, as shown by the high correlation between applying trial-and-error strategies, recalling similar problems, and starting to solve a problem by applying seemingly suitable formulae, and by the high number of positive responses to the latter item. An important issue here is that failure in assimilating more suitable strategies and understanding that problem solving is an inherently flexible process can lead to a shallow and incomplete comprehension of subjects like Mathematics, as discussed in [10].

Intra-group correlations also suggest that those applying one strategy successfully will apply others as well, while those who fail at using some strategies will likely fail at others too. It can thus be concluded that there are two, possibly overlapping, groups that need attention, consisting of those who have embraced an ineffective strategy, and those who have no strategy at all. The students in these two groups should be handled on an individual basis when possible, in order to better understand their particular situation and administer guidance for improvement.

The second group of items, the one concerning motivation and metacognitive abilities, revealed that a considerable proportion of the students have obviously deficient metacognitive strategies, rarely thinking about the efficiency of their learning process or analyzing what they have learned after solving a problem. Also, an equally important issue is the fact that almost one third of students give up when they encounter difficulties or when the problem seems too hard, and the correlation between these two items and the Mathematics GPA might suggest that their academic results have a significant impact on their self-concept and self-efficacy. Studies [6][7][8] have shown that self-efficacy is highly correlated with performance; hence a deficit in this area is of the utmost importance and should be tended to immediately.

There are intra-group correlations here as well, between the two items relating to quitting, and between thinking about the efficiency of the learning process and analyzing the knowledge acquired after solving a problem. Just like before, the correlations suggest that there are students who are well motivated and have strong metacognitive abilities, but on the other hand there are those whose problems are acute, and who require immediate attention, should they have any chance of correction.

There are some interesting inter-group correlations as well, between strategies and metacognitive abilities, showing that at least a few students are good self-regulated learners. This is encouraging, but the majority who do have deficiencies should be assisted in correcting them. There are several ways in which these Self-Regulation deficiencies, be they related to strategies or metacognitive abilities, could be tackled. Studies have shown that explicitly teaching problem solving strategies can greatly improve the students' efficiency and understanding in areas like Mathematics [11], Physics [12][13], or Chemistry[14]. Also, others have concluded that by prompting students to discover new problem solving methods, and sometimes directly teaching such methods, their flexibility with respect to this task can be enhanced [15]. Furthermore, some researchers consider that even metacognitive abilities can be improved by teaching [16][17], and that, for certain students, explicit instruction and support is paramount to overcoming self-regulatory deficiencies [18][19]. Here are four principles to be considered when embedding Self-Regulation in the instructional process [20]: (a) guide learners to prepare and structure an effective learning environment, (b) organize instruction and activities to facilitate cognitive and metacognitive processes, (c) use instructional goals and feedback to present student monitoring opportunities, and (d) provide learners with continuous evaluation information and occasions to self-evaluate.

Another potential solution involves a wider use of computers and Web-based tools. Not only have computer programs been proven to enhance students' problem solving abilities [21][22], but they can also stimulate motivation [23] and directly support Self-Regulated learning [24], thus constituting a valuable instrument in Self-Regulation teaching, were such endeavor to be pursued.

The results were also matched against possibly relevant factors, like gender, age, grade, parents' education, or GPA. Special attention was given to gender, the only factor for which a significant correlation to some items was identified. Gender differences as to ability and academic performance constitutes the central subject of numerous studies, and the results obtained vary widely. However, a meta-analysis of several articles covering this matter [25] has shown that the differences are generally task related and close to insignificant. The results of this study show that answers given by females and males were similar for all items with a few exceptions. It can be concluded that females employ different strategies, preferring to read the problem several times as opposed to considering several problem solving methods and applying various strategies according to the problem at hand, which are mostly preferred by males. The results are consistent with those of other studies [26] which show that females are generally less flexible in the strategies they use. Consequently, focusing on the same methods and strategies over and over again in the instructional process will have negative effects on girls, further limiting their flexibility, and is thus a practice that must be avoided. Studies [5] also show that females are better self-regulated learners than males but the results obtained here cannot support the idea, as there is no evidence of any gender-bias.

5. Conclusion

The purpose of this pilot study was to assess students' strategies in problem solving process and their motivation and metacognitive abilities. The results revealed that there are a few problems that must be tended to, like the high give-up rate, the use of inefficient strategies, and deficient metacognitive abilities in some students. Corrective actions were proposed, involving explicit teaching of Self-Regulation and possibly the use of Web-based tools.

References

[1] http://oxforddictionaries.com, last accessed 17th March 2011.

[2] http://dexonline.ro, last accessed 17th March 2011.

[3] Hayes J. (1980). *The complete problem solver*. The Franklin Institute, Philadelphia.

[4] Zimmerman B.J. (2000). Attaining Self-Regulation: A Social Cognitive Perspective**.** *Handbook of self-regulation*, Academic Press, San Diego, 13-39.

[5] Zimmerman B.J., Martinez-Pons M. (1990). Student Differences in Self-Regulated Learning: Relating Grade, Sex, and Giftedness to Self-Efficacy and Strategy Use. *Journal of Educational Psychology*, 82 (1), 51-59.

[6] Pajares F., Miller M. D. (1994). Role of Self-Efficacy and Self-Concept Beliefs in Mathematical Problem Solving: A Path Analysis. *Journal of Educational Psychology*, 86 (2), 193-203.

[7] Pajares F., Kranzler J. (1995). Self-Efficacy Beliefs and General Mental Ability in Mathematical Problem-Solving. *Contemporary Educational Psychology*, 20, 426-443.

[8] Pajares F., Graham L. (1999). Self-Efficacy, Motivation Constructs, and Mathematics Performance of Entering Middle School Students. *Contemporary Educational Psychology*, 24, 124-139.

[9] Linder R. W., Harris B. R. (1993). Teaching Self-Regulated Learning Strategies. *Convention of the Association for Educational Communications and Technology, New Orleans.*

[10] Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. *Handbook for Research on Mathematics Teaching and* Learning, MacMillan, New York, 334-370.

[11] Schurter W. A. (2002). Comprehension monitoring: An aid to mathematical problem solving. *Journal of Developmental Education*, 26 (2), 22-33.

[12] Larkin J. H., Reif F. (1979). Understanding and teaching problem solving in physics. *European Journal of Science Education*, 1, 191-203.

[13] Wright D. S., Williams C. D. (1986). A WISE Strategy for Introductory Physics. *The Physics Teacher*, 24, 211-216.

[14] Sutherland L. (2002). Developing problem solving expertise: The impact of instruction in a question analysis strategy. *Learning and Instruction*, 12, 155-187.

[15] Star J. R., Rittle-Johnson B. (2008). Flexibility in problem solving: The case of equation solving. *Learning and Instruction*, 18 (6), 565-579.

[16] McCombs, B.L. (1989). Self-regulated learning and academic achievement: A phenomenological view. *Self regulated learning and academic achievement: Theory, research, and practice*, 51–82.

[17] Puntambekar, S. (1995). Helping students learn 'how to learn' from texts: Towards an ITS for developing cognition. *Instructional Science*, 23, 163–182.

[18] Ertmer, P.A., Newby, T.J. (1996). The expert learner: Strategic, self-regulated, and reflective. *Instructional Science*, 24, 1–24.

[19] Lebow, D. (1993). Constructivist values for instructional systems design: Five principles toward a new mindset. *Educational Technology Research and Development*, 41, 4–16

[20] Ley K., Young D. (2001). Instructional principles for self-regulation. *Educational Technology Research and Development*, 49 (2), 93-103.

[21] Harskamp E.G., Suhre S.G.M. (2006). Improving mathematical problem solving: A computerized approach. *Computers in Human Behavior*, 22 (5), 801-815

[22] Karal H., Cebi A., Peksen M. (2010). The web based simulation proposal to 8th grade primary school students' difficulties in problem solving. *Procedia - Social and Behavioral Sciences*, 2 (2), 4540-4545

[23] Wang S.K., Reeve T. (2006). The Effects of a Web-Based Learning Environment on Student Motivation in a High School Earth Science Course. *Educational Technology Research and Development*, 54 (6), 597-621

[24] Dabbagh N., Kitsantas A. (2005). Using Web-based Pedagogical Tools as Scaffolds for Self-regulated Learning. *Instructional Science*, 33 (5), 513-540.

[25] Hyde J.S., Fennema E., Lamon S.J. (1990). Gender Differences in Mathematics Performance: A Meta-Analysis. *Psychological Bulletin*, 107 (2), 139-155.

[26] Gallagher A.M., De Lisi R., Holst P.C., McGillicuddy-De Lisi A.V. (2000). Gender Differences in Advanced Mathematics Problem Solving. *Journal of Experimental Child Psychology*, 75, 165–190.

Author

Alexandru Brad, Babeş-Bolyai University, Masters Program, Department of Computer Science, Cluj-Napoca, Romania, e-mail: brad.alexandru@gmail.com

Acknowledgement

I would like to thank Ms Liliana Ciascai for her support and assistance.