THE COMPARISONS OF QUANTITATIVE AND QUALITATIVE PROBLEMS ON STUDENTS' PHYSICS ACHIEVEMENT

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ABSTRACT: Problem solving is quite important for physics and physics education. Besides, it is essential for students to develop the scientific and analytical thinking processes. These processes can be taught to students with the help of the scientific and analytical thinking. Generally, instructors solve some fundamental quantitative problems regarding the subjects after they teach the subjects in the traditional instruction model. Students also prefer to memorize some solution ways of the problems by using basic equations or formulas concerning the problems instead of learning and understanding the solution ways of the problems. These kinds of approaches do not lead to sufficient learning for the students. Solely, knowing the fundamental equations/formulas are not enough for problem solving. The instructors need to more concentrate on teaching of the qualitative problem solving. Therefore, this study investigated the effects of quantitative and qualitative problems on students' problem-solving performances. The study was conducted with 80 university students. The students were asked four classical physics problems and 20 multiple choice questions in the final examination. The content of classical problems was about “Newton's Laws” and “Work and Energy”. Students' classical physics problem solutions with the help of designed assessment rubric and determined problem solving strategy steps were analyzed and reported. Some suggestions in the light of investigation were presented in the end of the research.

Keywords: higher education, physics education, problem solving, problem solver

INTRODUCTION

"Problem solving as a goal-directed behavior requires an appropriate mental representation of the problem and the subsequent application of certain methods or strategies in order to move from an initial, current state to a desired goal state" (Metallidou, 2009, p.76). Problem solving generally is a decision-making process (Gok, 2010a). Metacognition also plays an important role in this process (Gok, 2014). Problem solving refers to defining physics concepts and/or fundamental principles, analyzing mathematics and physics procedures, and evaluating the solution way.

Rosengrant, Van Heuvelen, & Etkina (2005) stated that problem solving is a scientific ability. In order to develop the scientific ability, therefore the instructors should teach to students both quantitative and qualitative problem solution ways. Problems could be separated into quantitative problems and qualitative problems. The quantitative problem refers to the numerical variables and units in the problem statements. Students are quantitatively asked to solve the quantitative problems by using concerning equations or formulas with the help of the given numerical variables and units. Consequently, they are expected to find the numerical results. The qualitative problem does not refer to the numerical variables and units in the problem statements. This kind of problem only uses the symbolic characters in the problem statements. Students are qualitatively asked to solve the qualitative problems by using concerning equations or formulas with the help of the given symbols. Eventually, they are expected to find the qualitative results based on the equations or formulas. Ploetzner and Beller (2000) examined the effects of using qualitative and quantitative concepts in classical mechanics on students' problem-solving performance. They defined the strategies to support qualitative and quantitative problem solving. At the end of their research, they revealed that the qualitative problem solving is more effective on physics instruction than the quantitative problem solving.

Several physicists (Chi, Feltovich, & Glaser, 1981; Dufrense, Gerace, & Leonard, 1997; Gok, 2015; Walsh, Howard, & Bowe, 2007) investigated the differences in problem solving between expert problem solvers and novice problem solvers. Expert problem solvers redefine the problem situation, describe the fundamental principle(s) or concept(s) of the problem, write the known and unknown variables in the problem, draw a sketch/picture or a diagram for the visual understanding if it is needed, determine the mathematical equation(s)/formula(s) and lastly check logically the solution procedure. Shortly, they solve the problems in a very structured way with the help of scientific approach. On the other hand, novice problem solvers quickly focus on the usage of quantitative numerical variables and ignore the conceptual information. Briefly they prefer to use plug and chug approach or no clear approach. Docktor and Heller (2009) also revealed the differences between expert problem solvers and novice problem solvers. These differences were process and knowledge organization.

Walsh et al. (2007) analyzed the problem-solving approaches of the students. Problem solving approaches were separated into four categories including scientific approach, plug and chug (structured and unstructured manner), memory-based approach, and no clear approach. Some popular physics textbooks presented alternative problem-solving approaches at the end of chapter problems. Young and Freedman's approach (2008) was to (a) identify, (b) set up, (c) execute, and lastly (d) evaluate. Tipler and Mosca's approach (2007) was to (i) picture the problem, (ii) solve the problem, and finally (iii) check the problem. These problem-solving approaches provide thinking like a physicist for both expert and novice problem solvers (Van Heuvelen, 1991).

Problem solving is a very complex process and there is no standard way to evaluate and analyze problem solving performance of the students. Many studies (Docktor & Heller, 2009; Fink & Mankey, 2010) investigated the evaluation of problem solving approaches while the expert and novice problem solvers were solving the qualitative and quantitative problems as homework, class-quizzes, mid-term and final examinations. Students' problem-solving approaches were analyzed by using some assessment rubrics given in the mentioning studies. Fink and Mankey (2010) identified an assessment rubric/template including "given", "find", "relevant equations", "detailed sketch", "symbolic solution", "numeric solution", "dimensions", and "order of magnitude". Docktor and Heller (2009) also developed an assessment rubric to evaluate and analyze problem solvers' written solutions about physics process based on "useful description", physics approach", "specific application of physics", "mathematical procedures", and "logical progression". These assessment rubrics reveal the relationships between learning outcome and assessment for the physics courses. Fink and Mankey (2010) indicated "the problem-solving template promises to track the process and will help to assess the development of problem-solving skills essential for doing physics"(p.278).

Many studies revealed that the students could learn quantitative problem solving, but they could not develop conceptual understanding as well (Byun & Lee, 2014; Gok, 2014; Gok, 2015; Heller, Keith, & Anderson, 1992; Heller & Hollabaugh, 1992; Thacker, Kim, Trefz, & Lea, 1994; Van Heuvelen & Zou, 2001). The students were generally taught the physics courses with traditional teaching methods, therefore they focused on memorizing the formula(s)/equation(s) instead of learning the fundamental concept(s)/principle(s) while they were solving quantitative problems or they preferred to memorize the solution ways of the problems without following systematic strategy (Gok, 2015). As a result, the students could not sufficiently enhance the problem-solving performance while problem solving with the help of traditional teaching methods. The quantitative problem solving does not develop both deep conceptual understanding regarding fundamental principle(s) and problem-solving skills of the students.

The problem-solving strategy steps were developed because the students were not good at problem solving adequately. Polya (2009), an expert mathematician, explained problem solving as four steps in *How to Solve It*. The first step is to understand the problem, the second step is to devise a plan, the third step is to carry out the plan, and the last step is to look back. Van Heuvelen (1991) determined problem solving strategy steps as pictorial representation, physical representation, mathematical representation and solution, and finally evaluation by using multiple representations based on OCS (Overview, Case Study) Physics and a set of Active Learning Problem Sheets (the ALPS kit). Problem solving strategies were divided into five steps by Heller et al. (1992). The first step is to visualize the problem, the second step is to describe problem statement, the third step is to plan a solution, the fourth step is to execute the plan, and the last step is to check and evaluate. Reif, Larkin, and Brackett (1976) described problem solving strategy as description, planning, implementation, and checking. Problem solving procedures were separated into three major steps which were initial problem analysis, construction of a solution, and finally checking solutions respectively (Reif, 1995). Recently Gok (2015) identified problem solving strategy steps including a) identifying fundamental principle(s), b) solving and c) checking, respectively.

Consequently, the problem-solving strategy steps should be taught in order to enhance problem solving skills of the students, understand the reasons about the physical process, and think about the fundamental principle(s)/concept(s) regarding both qualitative problems and quantitative problems. In this context, the main purpose of the present study was to examine and compare the quantitative and qualitative problem-solving skills of the students with the help of an assessment tool.

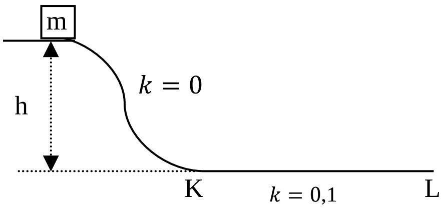
METHODS

The qualitative and quantitative problem-solving skills of the students were compared by problem solving strategy steps of Heller et al. (1992). The present study was conducted with 80 university freshman students enrolled in introductory calculus-based physics course at a state university in Turkey. The data of the research was collected with physics final examination. The students participated in the same classroom were randomly separated into two groups for only physics final examination, the final examination consisted of four classical problems and 20 multiple-choice questions. The classical problems and the multiple-choice questions were evaluated out of 40 and

60 points, respectively. The classical problems were only evaluated and analyzed in this study. The half of the students was asked four quantitative problems while the rest of the students were asked four qualitative problems. The qualitative and quantitative problem statements were similar for both groups. The distribution of the problems is given as follows: The first two problems covered "Newton's Laws of Motion" and the other problems consisted of "Work and Energy". An example problem was given in Figure 1.

Quantitative Problem

An object of mass m=1kg is released from height of h=1m and then it stops at the point L as presented in Figure. The horizontal surface is frictional (k≠0). What is the length KL?



Qualitative Problem

An object of mass m is released from height h and then it stops at the point L as presented in Figure. The horizontal surface is frictional (k≠0). What is the length KL?

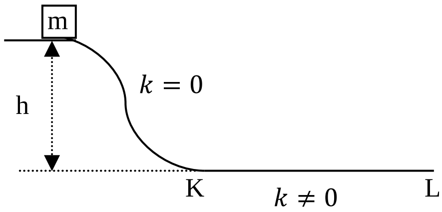


Figure1. An Example of the Qualitative and Quantitative Problem in the Final Examination

As mentioned before, the quantitative and qualitative problems were analyzed according to problem solving strategy steps developed by Heller et al., (1992). Problem solving was examined into five steps as follows:
The first step is to visualize the problem. The students are expected to describe the problem statement with the help of appropriate representations such as the usage of symbols for quantities, defining coordinate axes, drawing a graph or sketch etc.

The second step is to describe the problem statement with the help of physics terms. The students are expected to determine the known and unknown variables symbolically, to identify fundamental concepts/principles and to analyze by dividing the problem into smaller sub-problems.

The third step is to plan a solution. The students are expected to write the appropriate equations/formulas based on determined problem statement in order to find desired unknown variable by using known and given variables. Besides they are expected to determine the boundaries of the problem for problem solving.

The fourth step is to execute the plan. The students are expected to solve the problem by means of mathematical rules and defined equations/formulas. There are two conditions in this step for the present research. Firstly, the students are asked for finding a qualitative statement based on equations/formulas for final result symbolically if the students are asked qualitative problems. Secondly, the students are asked for finding numerical a final result if the students are asked quantitative problems.

The last step is to check and evaluate the solution way. The students are expected to control reasonableness of their answer such as unit, sign, magnitude etc. They are also expected to control the overall solution way of the quantitative and qualitative problems.

A rubric sheet according to problem solving strategy steps was developed for evaluating quantitative and qualitative problem-solving performance of the students. The purpose of this rubric was to evaluate each step of problem solution ways instead of focusing on final result of the problems. Thus, instructors may evaluate the learning process and cognitive psychology of the students, may analyze mathematical and physics thinking skills of the students, and may determine the difference between "expert" and "novice" problem solvers in problem solving processes. The assessment rubric provides the instructors to diagnose the problem solution ways of the students in terms of organizing the problem statement into a useful description, identifying appropriate fundamental physics principles or concepts, applying to the problem specific conditions, using mathematical procedures, and finally appraising the overall solution procedures.

Each step of the problem-solving strategy steps is evaluated out of 2 points. Each step consists of two items. Also, each item of the steps is evaluated out of 1 point. These steps can be evaluated with the help of computers (Gok, 2010b; Hsu & Heller, 2009) according to the number of students (N>50) if it is needed. The score rubric sheet was given as Appendix A. The similar rubric sheet was designed by Docktor and Heller (2009). The author will conduct the validity, reliability, and utility of the score rubric sheet in next studies. A student can only take maximum 40 points for solving of asked four classical problems in the final examination. The problem-solving strategy steps and assessment criterion of the items were listed as follows:

Step I: Visualize the problem

a) Draw a sketch or a picture of the problem situation, if it is needed.
b) Identify the known and unknown variables

Assessment 1: *Write the name of variables, conceptually*
Draw a picture or a sketch if it is needed

Step II: Describe the problem

a) Symbolically specify the known and unknown variables
b) State the physical situation with a diagram and remark axes on a graph if it is needed

Assessment 2: *Mark the symbol of the variables*
Draw a diagram or coordinate system if it is needed

Step III: Plan a solution

a) Begin to determine fundamental principles and concepts
b) Select the mathematical procedures based on required formulas

Assessment 3: *Determine the fundamental principle(s) of the problem*
Write the needed equation(s)/formula(s) to solve the problem

Step IV: Execute the plan

a) Systematically start problem solving by using appropriate mathematical procedures
b) Find desired unknown variable(s)

Assessment 4: *Solve an equation symbolically for finding the unknown variable*
Solve an equation numerically for finding the unknown variable

Step V: Check the solution way

a) Check the solution procedures
b) Verify the magnitude and unit of the answer

Assessment 5: *Write the unit of variables*
Represent the vector and dimensional analysis if it is needed

RESULTS AND FINDINGS

The problem solving of qualitative problem solvers and quantitative problem solvers were analyzed as shown in Appendix B and examined according to problem solving strategy steps as follows:

The First Step: Visualize the Problem

The qualitative problem solvers used more visualizing than the quantitative problem solvers as presented in Figure 2. The usage rate of the pictorial representation including identifying the known and unknown variables for the qualitative problem solvers was higher than 30%. This ratio was lower than 20% for quantitative problem solvers for the first item. Both qualitative problem solvers and quantitative problem solvers did not need to draw a picture or a sketch with respect to problems for the second item.

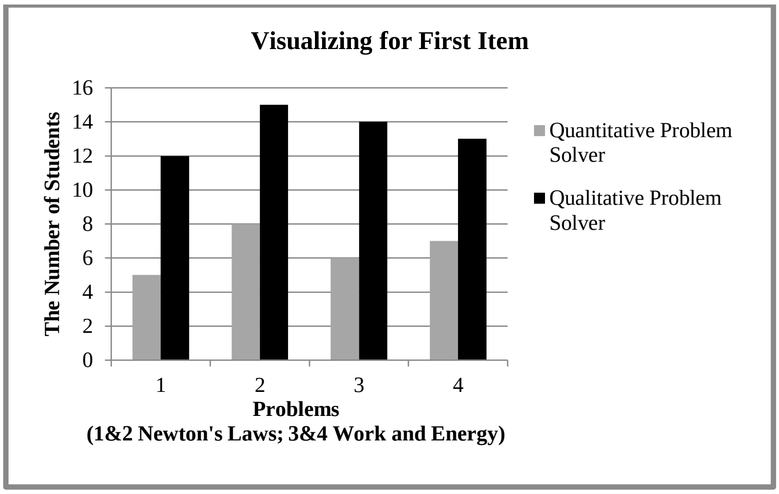
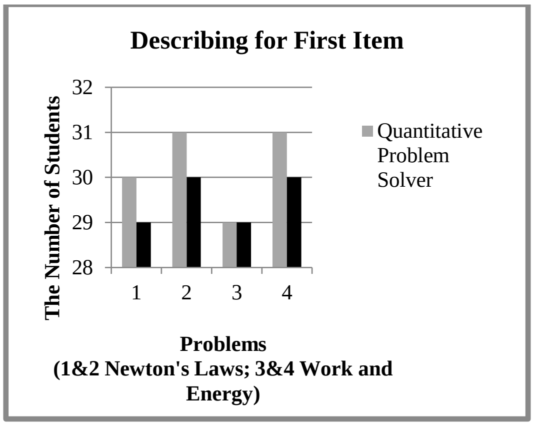


Figure 2. The Usage of First Step by Problem Solvers

The Second Step: Describe the Problem

Both qualitative and quantitative problem solvers (approximately 70%) for the first item could describe symbolically as shown in Figure 3. Besides nearly of 70% the qualitative and quantitative problem solvers included in the groups drew the force, motion and energy diagrams concerning Newton's Laws and Work and Energy problems for the second item.



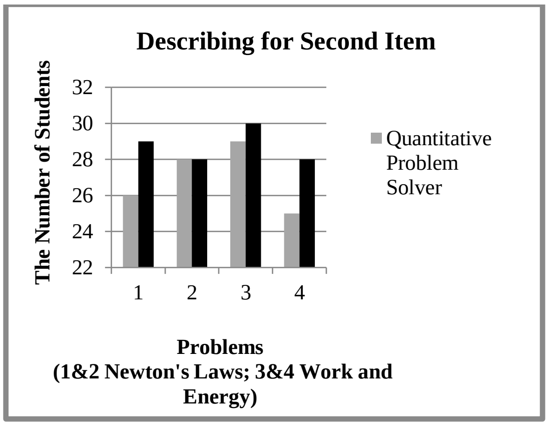


Figure 3. The Usage of Second Step by Problem Solvers

The Third Step: Plan a Solution

Approximately 10% of the quantitative problem solvers defined the fundamental principle(s) of the problem while 35% of the qualitative problem solvers for the first item identified the fundamental principle(s) of the problem as demonstrated in Figure 4. Besides, nearly 65% of both qualitative problem solvers and quantitative problem solvers wrote the needed equation(s)/formula(s) to solve problems for the second item.

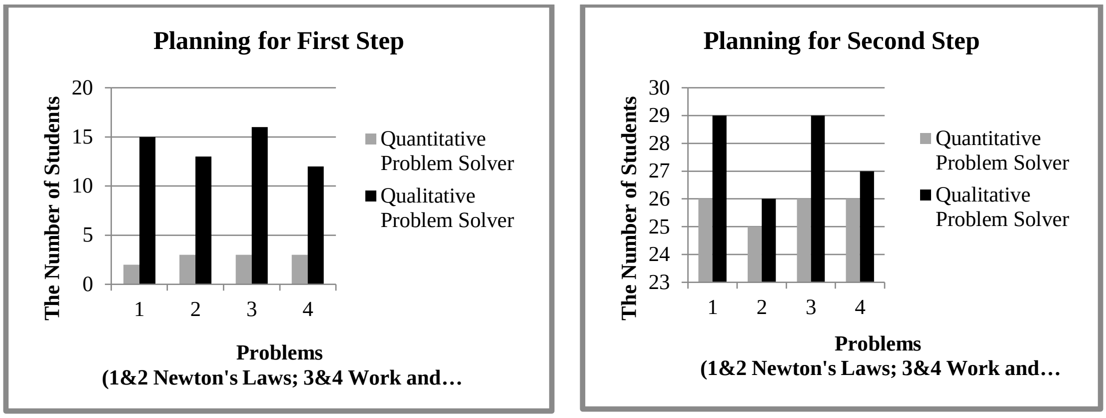


Figure 4. The Usage of Third Step by Problem Solvers

The Fourth Step: Execute the Plan

Roughly 15% of the quantitative problem solvers for the first item solved with the help of using an equation symbolically for finding the desired unknown variable while 55% of the qualitative problem solvers solved by means of using an equation symbolically for finding the desired unknown variable as shown in Figure 5. But the qualitative problem solvers could not solve an equation numerically for finding the desired unknown variables while the half of quantitative problem solvers could solve the problems in average for the second item. Besides the solutions of the qualitative problem solvers were evaluated out of 2 points for only the first item.

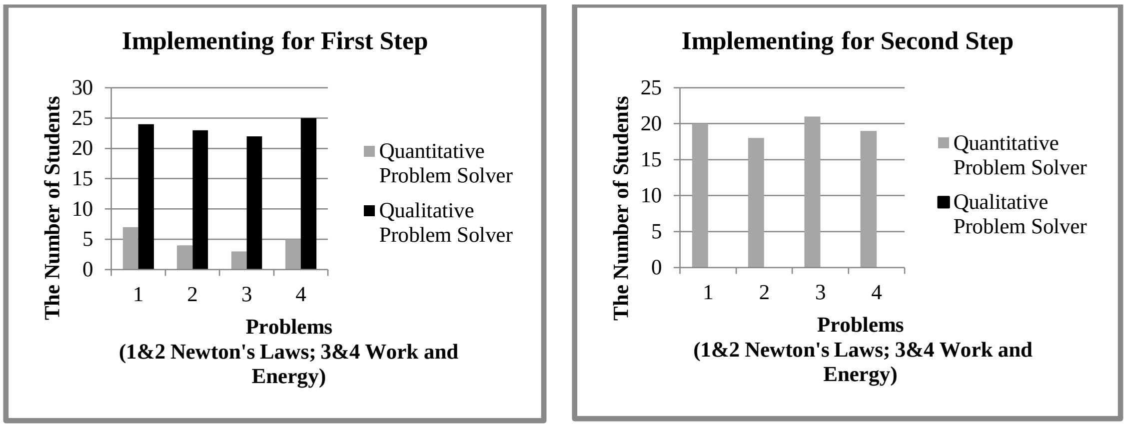


Figure 5. The Usage of Fourth by Problem Solvers

The Fifth Step: Check the Solution Way

Approximately 30% of the quantitative problem solvers checked the units of variables while the qualitative problem solvers could not mark the unit of variables for the first step. Besides both the qualitative problem solvers and the quantitative problem solvers could not represent the vector and dimensional analysis of the answers as presented in Figure 6.

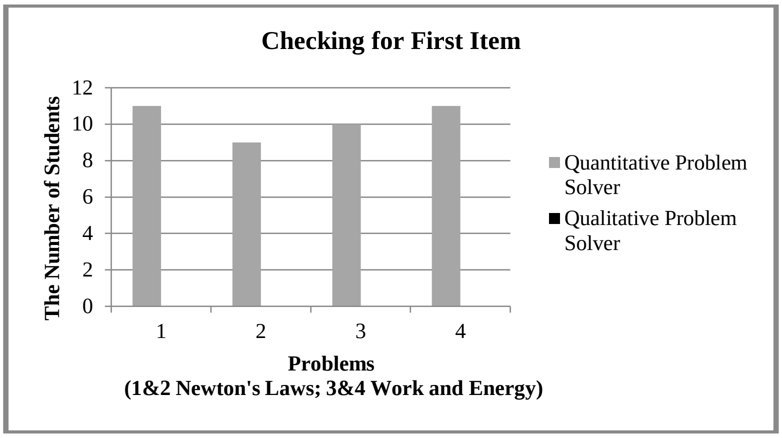


Figure 6. The Usage of Fifth Step by Problem Solvers

CONCLUSION

Qualitative and quantitative problems were evaluated and analyzed according to problem solving strategy steps "useful description, physics approach, application of physics, mathematical procedures, and finally logical progression" developed by Heller et al. (1992). These steps were important to interpret the cognitive psychology of the students, to monitor and evaluate mathematical and physics thinking skills of the students, and finally to analyze the difference in problem solving processes between experienced problems solvers "expert" and inexperienced problem solvers "novice". In this research, the approaches of the qualitative and quantitative problem solvers while solving physics problems were analyzed. Therefore, an assessment instrument for scoring rubric sheet was designed according to determined problem solving strategy steps. This rubric sheet easily provided the instructor to evaluate the problem-solving performance of the students by using determined criteria. Docktor & Heller (2009, p.16) reported "the rubric provides more meaningful information than standard grading by indicating areas of student difficulty that can be used to focus coaching and improve problem writing".

When the results of the research were interpreted to defined problem solving strategy steps it could said respectively that approximately 25% of qualitative and quantitative problems solvers wrote the names of known and unknown variables (force, net force, weight, mass, acceleration, work, energy, kinetic energy, potential energy, power etc.) while both problem solvers did not draw a picture or a sketch for visualizing step. The quantitative and qualitative problem solvers could describe approximately 70% the symbol of the variables ($\vec{F}$ for $force, m$ for $mass, \vec{a}$ for $acceleration,$ $\vec{v}$ for $velocity, W$ for $work$ etc.) and many problem solvers drew force "free-body" and energy diagrams or a coordinate system of asked problems for describing step.

10% of problem solvers determined only fundamental principle(s)/concept(s) (Newton's First Law, Newton's Second Law, and Newton's Third Law, Contact Forces, Work-Kinetic Energy, Conservation of Energy etc.) of the problem while nearly 65% of qualitative problem solvers and quantitative problem solvers wrote the needed equation(s)/formula(s) ($\vec{F} = m\vec{a}, \vec{F}_{net} = m\vec{a}, W = \Delta K, W = \vec{F}\Delta\vec{x}$ etc.) in order to solve problems for planning step. Approximately 55% of the qualitative problem solvers symbolically solved by means of using an equation for finding desired unknown variable. This ratio for quantitative problem solvers was quite low. Half of the quantitative problem solvers focused on the numerical results of the problems and nearly 55% of the qualitative problem solvers tried to solve problems with the help of equation(s)/formula(s) for finding desired unknown variables for implementing step. For checking step, 30% of the quantitative problem solvers controlled the units ($^{m}/_{s^2}$ for $acceleration, ^{m}/_{s}$ for $velocity, kg$ for $mass, N$ for $force,$ J for $energy,$ $^{J}/_{s}$ for $power$ $etc.$), signs (x for $distance, h$ for $height, \mu_k$ for $coefficient$ of $kinetic$ $friction$ etc.), and magnitudes (scalar and vector quantities) of the variables while none of qualitative problems solvers did check the variables. Both quantitative problem solvers and qualitative problem solvers could not also perform the vector and dimensional analysis.

When the results of the research were generally discussed, it could be said that the quantitative problem solvers immediately tried to reach a conclusion by using needed equation(s)/formula(s). The research results of Gok (2015), Gok (2013), Reif (1995), and Van Heuvelen (1991) supported the present research results. Because it was important to find correct and/or meaningful numerical answer for them on the other hand the qualitative problem solvers showed tendency to write everything about problems-solving (concepts, principles, formula/equations etc.).

Consequently, the logical procedures of the problem solving are crucial to learn for both the qualitative problem solvers and the quantitative problem solvers, besides the instructors should present students the logical procedures and teach the students the alternative solution ways of problem according to problem solving strategy steps.

RECOMMENDATION

Some suggestions in the light of the research results might be presented as follows: a) instructors should teach students how to solve a problem and they should explain the students how to use problem solving strategy steps on a sample problem; b) they should encourage the students to use problem solving strategy; c) the instructor should focus on logical procedures instead of finding numerical results by problem solving; d) they should motivate the students to think about the problem solving approaches instead of memorizing the formula(s)/equation(s).

NOTE

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REFERENCES

Byun, T., & Lee, G. (2014). Why students still can't solve physics problems after solving over 2000 problems. *American Journal of Physics, 82*(9), 906-913.

Chi, T., Feltovich, P., Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognition Science*, *5*, 121-152.

Docktor, J., & Heller, K. (2009). Robust assessment instrument for students’ problem solving. *Proceedings of the NARST Annual Meeting*. Garden Grove, California, USA.

Dufrense, R., Gerace, W., & Leonard, J. (1997). Solving physics problems with multiple representations. *Physics Teacher*, *35*, 270-275.

Fink, J. M., & Mankey, G. J. (2010). A problem-solving template for integrating qualitative and quantitative physics instruction. *The Journal of General Education, 59*(4), 273-284.

Gok, T. (2010a). The general assessment of problem solving processes and metacognition in physics education. *Eurasian Journal of Physics and Chemistry Education*, *2*(2), 110-122.

Gok, T. (2010b). A new approach: Computer-assisted problem-solving systems. *Asia-Pacific Forum on Science Learning and Teaching, 11*(2), 1-22.

Gok, T. (2013). A comparison of students' performance, skill and confidence with peer instruction and formal education. *Journal of Baltic Science Education, 12*(6), 747-757.

Gok, T. (2014). Students' achievement, skill and confidence in using stepwise problem-solving strategies. *Eurasian Journal of Mathematics, Science & Technology Education, 10*(6), 617-624.

Gok, T. (2015). An investigation of students' performance after peer instruction with stepwise problem-solving strategies. *International Journal of Science and Mathematics Education, 13*, 561-582.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics, 60*(7), 627-636.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*(7), 637-644.

Hsu, L., & Heller, K. (2009). Computer problem-solving coaches. *Proceedings of the NARST Annual Meeting*. Garden Grove, California, USA.

Metallidou, P. (2009). Pre-service and in-service teachers' metacognitive knowledge about problem-solving strategies. *Teaching and Teacher Education, 25*, 76-82.

Ploetzner, R., & Beller, S. (2000). Teaching and supporting the use of qualitative and quantitative concepts in classical mechanics. In Gleitman, L., & Joshi, A. K. (Eds.), *Proceedings of the Twenty-Second Annual Conference of the Cognitive Science Society.* Mahwah, NJ: Lawrence Erlbaum.

Polya, G. (2009). *How to solve it: A new aspect of mathematical method*. New York: Ishi Press.

Reif, F., Larkin, J. H., & Brackett, G. C. (1976). Teaching general learning and problem-solving skills. *American Journal of Physics, 44*(3), 212-217.

Reif, F. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought processes. *American Journal of Physics, 63*(1), 17-32.

Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2005). Case study: Students’ use of multiple representations in problem solving. *Physics Education Research Conference*. Salt Lake City, Utah.

Thacker, B., Kim, E., Trefz, K., & Lea, S. M. (1994). Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses. *American Journal of Physics, 62*(7), 627-633.

Tipler, P., & Mosca, G. (2007). *Physics for scientists and engineers (6th ed.).* New York: W. H. Freeman & Co.

Van Heuvelen, A. (1991). Overview, case study physics. *American Journal of Physics, 59*(10), 898-907.

Van Heuvelen, A., & Zou, X. (2001). Multiple representations of work-energy processes. *American Journal of Physics*, *69*(2), 184-194.

Walsh, L. N., Howard, R. G., & Bowe, B. (2007). Phenomenographic study of students' problem solving approaches in physics. *Physical Review Special Topics-Physics Education Research*, *3*(020108), 1-12.

Young, H., & Freedman, R. (2008). *University physics* (12 th ed.). Upper Saddle River, NJ: Pearson.