The Effects of Problem Solving Instruction on Physics Achievement, Problem Solving Performance and Strategy Use

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Abstract

This study has investigated the effects of problem solving instruction on physics achievement, problem-solving performance and strategy use in an introductory physics course at university level. In this study, pretest-posttest and quasi-experimental design with nonequivalent control group was used. Two groups of student teachers (n=74) participated in this study. During the 8-week study, one group received the strategy instruction while the other group acted as control. Data of the study were collected by Physics Achievement Test (PAT), Problem-Solving Performance Test (PSPT) and Problem-Solving Strategies Scale (PSSS). Findings of the study indicate that strategy instruction was effective on physics achievement, problem-solving performance, and strategy use. The implications of these results for physics instruction are discussed.

Keywords: Physics education, Problem solving strategies, Strategy instruction.

Resumen

Este estudio ha investigado los efectos de la instrucción de resolución de problemas en logros de física, el rendimiento en solución de problemas y el uso de estrategia en un curso introductorio de física a nivel universitario. En este estudio, se utilizó el diseño de pretest y posttest cuasi-experimental con grupo de control no equivalente. En este estudio participaron dos grupos de profesores estudiantes (n = 74). Durante las 8 semanas del estudio, un grupo recibió la estrategia de instrucción, mientras que el otro grupo actuó como control. Los datos del estudio fueron recogidos mediante el Test de Logros en Física (PAT), el Test de rendimiento en solución de problemas (PSPT) y la Escala de Estrategias en solución de problemas (PSSS). Los resultados del estudio indican que la estrategia de instrucción es eficaz en en logros de física, en rendimiento de solución de problemas, y el uso de estrategia. Se discuten las implicaciones de estos resultados para la instrucción física.

Palabras clave: Educación en Física, Estrategias de resolución de problemas, Instrucción de estrategias.

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I. INTRODUCTION

One of the most important target of the modern education is to educate individuals who are overcoming the problems which they encountered in their daily lives and social lives on their own, in other words, individuals who can easily solve the problems which they encountered. Gagné [1] stated that educational programs had the important ultimate purpose of teaching students to solve problems-mathematical and physical problems, health problems, social problems, and problems of personal adjustment.

Serway and Beichner [2] strongly advise developing the skills necessary to solve a wide range problems in keeping with the statement "You do not know anything until you have practiced." said by R.P. Feynman, Nobel laureate in physics. They express that problem solving ability would be one of the main tests of knowledge of physics, and they advice trying to solve as many problem as possible.

Problem solving is usually defined as formulating new answers, going beyond the simple application of previously learned rules to create a solution [3]. Problem solving is an investigative task whereby the solver explores the solution path to reach a goal from given information [4]. According to Heller and Reif [5], that is an intellectually demanding activity of central importance in any science. All the sciences, both pure and applied, are centrally concerned with developing and systematizing knowledge useful for solving various kinds of problems. Problem solving is a complex, multi-layered skill, and not one that most students can be expected to develop unaided [6]. Hence, education in the sciences must address the crucially important task of teaching students to become more proficient problem-solvers [7].

The basic problem solving process is a linear, hierarchical process. Each step is a result of the previous step and a precursor to the next step. A popular method, teaching problem solving, involves the use of "stage models". Stage models are simplified lists of stages and steps used in general problem solving [8]. Polya's prescription for solving problems consists of four steps (adapted from [9]):

1. Understanding the problem (Recognizing what is asked for)

Example approaches for doing so: Asking yourself, "What am I looking for?" or "What information is given in the problem?"

2. Devising a plan for solving the problem (Responding to what is asked for)

Example approaches for doing so: Asking yourself, "Do I know a similar problem?", "Can I restate the problem?".

3. Carrying out the problem (Developing the result of the response)

4. Looking Back (Checking. What does the result tell me?)

Example approaches for doing so: Check the calculations and result or try to get the same result using a different method.

Whereas each of these steps are considered as separate skills, each step is categorized into sub skills. These skills can be considered as the analytical parts (heuristics) of the problem solving process which requires defining, investigating, reviewing and processing of the information regarding the problem. Somewhat synonymous term is "strategies". A problem-solving strategy is a technique that may not guarantee solution, but serves as a guide in the problem solving process [10].

As the research literature on problem solving is reviewed, it is seen that the individuals who use the problem solving strategies effectively and consciously were called as "expert problem solvers" and who can not use it sufficiently were called as "novice problem solvers". Differences among experts and novices had constituted a well foundation for the research done on problem solving in the subject areas such as physics, mathematics, and chemistry.

The research related to the problem solving in physics are focussed on two main titles. First one of these is the research regarding the comparison of the problem solving behaviour differences among expert and novice problem solvers [4, 11, 12, 13, 14, 15, 16, 17, 18]. According to the results obtained from certain research investigating the strategy use of the expert and novice problem solvers [4, 7, 11, 13, 19]. Experts have a tendency of firstly analyzing the problem qualitatively by depending on the fundamental physics concepts before passing to solve the problems by means of mathematical equations. Whereas, novices mostly start to solve the problem by means of mathematical equations, substitute the given variables, and then investigate the other equations where they can substitute the other quantitative variables.

Expert problem solvers proceed through the following four phases of analysis when they faced with a challenging quantitative problem (rather than a standard one which they recognize and remember the solution of it): conceptual analysis (orienting, exploring); strategic analysis (planning, choosing); quantitative analysis (executing, determining, answering); and meta-analysis (reflecting, checking, challenging, relating). In typical instruction, only quantitative analysis is explicitly modeled for students, leaving them to develop the other skills on their own [20]. And the reasearch existing in the second group is directed towards teaching problem solving strategies in order to make the novices become expert problem solvers [7, 19, 21, 22, 23].

One instructional method that has been used to address problem solving performance is explicit problem solving instruction. Explicit problem solving is instruction that directly teaches students how to use more advanced techniques for solving problems [22].

The studies related to explicit instruction of problem solving skills fall into two categories: (1) Laboratory-based experiments where students were extracted from a class and taught expert-like skills, and (2) Classroom-based experiments where an entire class was taught these skills [24]. Most problem solving studies have been set in laboratories, so few have taken place in actual classrooms. The following section will describe the details of our study in classroom-based format.

A. The Present Study

Mestre *et al*. [19] stated that two important goals of physics instruction were to help students achieve a deep, conceptual understanding of the subject and to help them develop powerful problem solving skills. In light of this statement, we designed our explicit problem solving instruction which is integrated content instruction.

In this study, we aimed to determine the effects of the explicit problem-solving strategy instruction on student teachers' physics achievement, problem-solving performance and the frequency of problem-solving strategy use. The following research questions were posed:

1. Is there any significant difference between the strategy and control groups' physics achievement?

2. Is there any significant difference between the strategy and control groups' problem solving performances?

3. Are there any significant differences in mean frequencies of problem solving strategy use between the strategy and control groups?

B. The Description of the Course "Physics II"

The Faculty of Education of Dokuz Eylul University offers a two semester introductory physics courses (called Physics I and Physics II) that are required by 6 different departments (e.g., Mathematics Education, Physics Education, Chemistry Education, Biology Education, Science Education, Computer Education and Instructional Technology). The course "Physics II" is one of the spring term compulsory courses for the first-year undergraduate programs of these departments. The course consists of four lesson hours (45 minutes) of lecture and two hours of laboratory activity per week. The content of the course is based on the knowledge acquired during the course "Physics I" and the book *Physics for Scientists and Engineers with Modern Physics 2* by Serway and Beichner [2]. The course focuses on fundamental concepts, laws and problems of the electricity and magnetism and covers about two-thirds of the book chapters in this level.

II. METHOD

A. Participants

In Turkey, access to university higher education requires to have a high school graduation and take highly selective National University Entrance Exam. Applicants are placed at a university program according to the exam scores and their options. Among the applicants' placed at four-year Chemistry and Biology Teacher Education Programs, exam scores are close to each other. This means that the applicants' background knowledge level related with Mathematics, Physics, Chemistry, and Biology was almost equal. For this reason, the researchers determined to implement this study with these programs' first-year students.

All the students who enrolled Physics II course were included in the research. The subjects of the research consisted of 74 first-grade students teachers who are students of Chemistry (n=37) and Biology Education (n=37) departments of Education Faculty in Dokuz Eylul University in Izmir (Turkey). 40 female (19 chemistry education and 20 biology education) and 34 male (17 chemistry education and 17 biology educations) students, whose ages ranged from 17 to 19, took part in this study.

B. Research Design

In this study, pre-test-post-test quasi-experimental design (classroom-based) with non-equivalent control group was used. There were one control and one experimental group, namely, the strategy group. Since Chemistry and Biology Education departments were not equivalent, they were assigned by lottery to strategy and control groups.

The strategy group received strategy plus traditional instruction and the control group received only traditional instruction.

Both groups were tested before and after the intervention to measure their physics achievement and the frequency of problem solving strategy use. Before and after the intervention, the researchers also examined the physics problem solving performance of strategy group.

Control variables were prior physics achievement, strategy use, and prior problem solving performance scores. The independent variable was the intervention (the strategy and/or the traditional instruction). The dependent variables were post-test physics achievement, problem solving performance and strategy use.

C. Materials

The data of this study were collected by Physics Achievement Test (PAT), Problem-Solving Performance Test (PSPT) and Problem-Solving Strategies Scale (PSSS). These measuring instruments were explained in detail below.

Physics Achievement Test

In the study, in order to determine the students' physics achievement, Physics Achievement Test (PAT) developed by the researchers was used. The instrument contained 34 five-option, multiple-choice questions. First six sections from the book *Physics for Scientists and Engineers with Modern Physics 2* by Serway and Beichner [2] were selected for this research. Major topics on test were respectively as follows: Electric Fields, Electric Potential, Gauss' Law, Capacitance and Dielectrics, Current and Resistance and Direct Current Circuits. The test was intended to determine the knowledges of the students related to the fundamental concepts, and their skills on recalling the relationships between the concepts, and applying them to the problems (see Appendix A). The Kuder-Richardson reliability of the test was found as .83.

Problem-Solving Performance Test

To assess student teachers' physics problem-solving performance, Problem-Solving Performance Test (PSPT) developed by the researchers was used before and after the intervention. This test included 5 multiple-step open-ended problems which were chosen from the books *Physics for Scientists and Engineers with Modern Physics 2* by Serway and Beichner [2] and *Fundamentals of Physics* by Halliday, Resnick, and Walker [25]. The problems (see Appendix B) covered in this test were related to the PAT topics.

PSPT was scored according to the four-criterion Performance Assessment Rubric (see Appendix C) developed by the researchers, with a maximum score of 12 points for each problem, 60 points totally. Rubric criterions were designed to measure the quality of problem solving. The PSPT was independently scored by two researchers. The interrater agreement was calculated using the following formula recommended by Posner, Sampson, Ward, and Cheney [26]:

$$R = \frac{number\,of\ agreements}{number\,of\ agreements + number\,of\ disagreements}\,x100$$

Interrater agreement was found as 0.86 on average for the two performance measures.

Problem-Solving Strategies Scale

Students were administrated the Problem-Solving Strategies Scale (PSSS) developed by the researchers before and after the intervention (Cronbach's Alpha=0.82). The scale contained a 35 Likert-type items that provided information on each student's frequency of strategy use (see Appendix D). The items were designed to fit into the four categories of the problem solving process prescribed by Polya [9]. The scale was provided to the students with these options: Always, Frequently, Sometimes, Rarely, Never. Ratings ranged from a high score of 5 (Always) to a low score of 1 (Never) with respect to frequency of strategy use (maximum score=175 and minimum score=35).

The scale consisted of four sub-scales including "understanding", "planning", "solving", "checking and evaluating". A brief description of the sub-scales is provided in Table I.

TABLE I. Descriptions of the PSSS sub-scales

Sub-scales	*Description*
Understanding	Rereading the problem. Paraphrasing the problem. Visualizing the problem. Imagining the problem (use concrete models). Determining the givens. Determining the desired quantities. Identifying the constraints. Determining the significant information. Making a simpler problem. Using the appropriate physics vocabulary.
Planning	Thinking aloud the solution of the problem. Creating alternative solution ways. Identifying the principles. Rules and laws about the problem. Dividing the problem into sub-problems. Determining the mathematical equations to solve the problem. looking for patterns
Solving	Selection of an appropriate solution. Using the rules. Principles and laws to obtain the desired quantity(ies). Using the mathematical equations to solve the problem. Using trial and error.
Checking and Evaluating	Checking the problem-solving pathway (algorithm). Checking the answer. Checking the magnitude and unit of the answer. evaluating the result

D. Intervention Materials

Turkish translated version of the book *Physics for Scientists and Engineers with Modern Physics* by Serway and Beichner (5^{th} edition) was used as a textbook. Approximately forty multistep physics problems were selected from this textbook for using in the strategy and traditional instruction sessions. During the instruction process, researcher scripts containing example problem solution (one per session, see Appendix E for an example) and problem solving work sheets developed by the researchers were used in the strategy group.

E. Procedure

The study was conducted during the spring term in Physics II course. The duration of the study was eight weeks from mid-February to mid-April. Pretest measures of physics achievement, problem-solving performance and problem-solving strategy use were collected in the first week of spring term. The students were asked to solve problems specifying their all ideas and behaviours during the problem-solving period in written expressions in details. The tests were not handed back or discussed and students' scores were not reported to them. During the intervention, the strategy group received explicit strategy plus traditional instruction in whole-class format for four lesson hours (45-minute) a week. Problem solving instruction composed of two training phases called strategy acquisition and strategy application used in the Montague & Bos' [27] study. The first phase of the intervention involved the strategy acquisition training. Strategy acquisition training was implemented during the first week of this term at three 45-minute training sessions. Guidelines for strategy acquisition training include the following steps:

1) Direct explanation: explaining the problem solving process and strategies to raise student awareness of the purpose and rationale of strategy use,

2) Modelling: modelling of the strategies by the teacher/researcher (by thinking-aloud),

3) Independent Practice: to give students opportunities to practice the strategies which they are being taught,

4) Explicit Feedback: to provide frequent feedback to students on the quality and the strengths of their strategy using.

These steps were followed until a 100% criterion in attaining the knowledge of process and strategy use. Second phase of the intervention consisted of eight 2-lecture hour traditional instructions and eight 2-lecture hour strategy application practices. During the second phase of the intervention, firstly, the course content instruction was given by the researchers in the first two-hour and then strategy application practices were implemented in the next two-hour for each eight week within the regularly scheduled physics lectures. During practice sessions to facilitate strategy application, students were given a problem solving work sheet which contained five-multistep problems related with the course subjects. They were strongly encouraged to solve these problems by using strategies taught and complete the worksheets by hand-written. Students worked individually. This format allowed them to work at their own pace. The teacher did not provide assistance in this process. Problem solutions were presented on the board by the volunteer students thinking aloud within the last 15 minutes of every session.

All completed work sheets were collected and examined to determine the extent to which students effectively used the strategies taught. In the first ten minutes of the next lesson, students received feedback showing how they had responded and corrections if necessary.

Students in the control group received only traditional instruction at the same instructional period with each lesson following the same instructional sequence like students in the strategy group. Students in the control group were encouraged to solve the same problems individually during the problem solving hours (two 45-minute lessons per week) without explicit problem solving instruction. The amount of the time allotted for the problem solving tasks was equal for both groups.

The strategy and traditional instruction implemented by the researchers who had almost equal professional experiences and were subject-area experts. The investigators arbitrarily selected the treatment and control groups between them. Because of having large groups, the course content-instruction was made by the lecture method for each group. Two groups were equally conditioned in the progression of the instructional period. In the explicit strategy instruction, researchers used the stages from Polya's prescription for solving problems. Outline of the four-stage problem-solving process and the strategies used in this study were presented in Table II.

TABLE II. Outline of the four-stage problem solving process.

1. Understanding the problem
- Read and reread the problem
- Determine the givens and desired quantities
- Identify the constraints in the problem
- Determine the significant information in the problem
- Restate the problem by different forms (paraphrase the problem. drawing figure(s). diagram or graph(s) about the problem)

2. Devising a plan
- Identify the principles. rules and laws about the problem
- Determine the appropriate mathematical equations to solve the problem

3. Carrying out the plan
- Use the mathematical equations to solve the problem

4. Looking back
- Checking the problem-solving pathway
- Checking the magnitude and the unit of the answer

The posttest measures were administered two days after the completion of the training. The test methodology and the time allotted for the posttest measures were equal to those of the pretest measures.

F. Analysis of Data

The collected data from the PAT and PSSS were analyzed by SPSS, 10.0 versions. Frequency, percentage, mean (*M*), standard deviation (*SD*), t-test were employed. All statistical tests reported in this paper were conducted with a significance level of $\alpha = 0.05$. The obtained data from PSPT were analyzed by hand.

III. RESULTS

There are three sub-sections to the presentation of the results. These subsections answer the research questions.

A. The Effects of Problem-Solving Instruction on Physics Achievement

At the beginning and end of the study, both strategy and control groups were asked to respond to PAT to measure their physics achievement. Means and standard deviations of pretest and posttest scores were calculated. Independent samples t-tests were employed to compare the groups' mean pretest and posttest scores respectively (see Table III).

TABLE III. Comparisons between strategy and control groups for PAT pretest and posttest

Measure	*Groups*	*n*	*M*	*SD*	*df*	*t-value*	*p-value*
Pretest	Strategy Group	37	5.08	1.36	72	.18	.85
	Control Group	37	5.02	1.17			
Posttest	Strategy Group	37	23.29	5.18	72	4.50*	.00
	Control Group	37	17.48	5.88			

Note: *Statistically significant (significance defined as $p < .05$).

Both groups had failure on the pretest, with means 5.08 (*SD*=1.36) for the strategy group and 5.02 (*SD*=1.17) for the control group. Analysis showed that there was no statistically significant difference between the groups' prior physics achievement, $t(72)=0.18$, $p>.05$. For the scores on the posttest, data analysis showed that students in the strategy group scored significantly higher (*M*=23.29, *SD*=5.18) than those in the control group (*M*=17.48, *SD*=5.88), $t(72)=6.29$, $p<.05$. Effect size was computed using Cohen's *d* to measure the magnitude of the intervention effect. Cohen's effect size value ($d=1.04$) was very large according to Cohen's standards (1988). Paired samples t-tests were used to test the differences between the pretest and posttest achievement measures for each group (see Table IV).

TABLE IV. PAT pretest-posttest comparisons for the strategy and control groups

Groups	*Pretest*		*Posttest*			*Cohen's*
	M	*SD*	*M*	*SD*	*t-value*	*d*
Strategy Group (*n*=37)	5.08	1.36	23.29	5.18	19.72*	3.24
Control Group (*n*=37)	5.02	1.17	17.48	5.88	12.74*	2.09

Note: *Statistically significant (significance defined as $p < .05$).

Results indicated that the differences from pretest to posttest for both groups were statistically significant $t(36)=19.72$, $p<.05$; $t(36)=12.74$, $p<.05$; for strategy and control groups, respectively). The Cohen's *d* effect sizes (3.24 and 2.09 for strategy and control groups, respectively) pertaining to these differences were very large.

B. The Effects of Problem-Solving Instruction on Problem-Solving Performance

In order to investigate whether or not there was a significant difference in the problem solving performance between two groups before and after the intervention, means and standard deviations of pre and posttest scores were calculated. The mean pretest scores were very close to each other (*M*=8.38, *SD*=2.70; *M*=8.22, *SD*=2.74, for strategy and control groups, respectively). Thus, both groups were equal on the aspect of problem solving performance before the intervention. On the other hand, the mean posttest score of the strategy group (*M*=44.70, *SD*=7.59) was higher than that of the control group (*M*=34.81, *SD*=8.58). *t*-tests were used to analyze the differences between the groups.

TABLE V. Comparisons between the strategy and control groups for PSPT pretest and posttest

Measure	*Groups*	*n*	*M*	*SD*	*df*	*t-value*	*p-value*
Pretest	Strategy Group	37	8.38	2.70	72	.25	.80
	Control Group	37	8.22	2.74			
Posttest	Strategy Group	37	44.70	7.59	72	5.25*	.00
	Control Group	37	34.81	8.58			

Note: *Statistically significant (significance defined as $p < .05$).

As shown from Table V, results for the pretest indicated no significant difference in performances between the groups, $t(72) = 0.25$, $p = .80$. But, on the posttest, there was statistically significant difference between the groups, which favoured the strategy group, $t(72)=5.25$, $p=.00$. Paired samples t-test was undertaken in order to test the differences between the pretest and posttest problem solving performance measures for the strategy and control groups.

TABLE VI. PSPT pretest-posttest comparisons for the strategy and control groups.

	Pretest		*Posttest*			*Cohen's*
Groups	*M*	*SD*	*M*	*SD*	*t-value*	*d*
Strategy Group (*n*=37)	8.38	2.70	44.70	7.59	33.80*	5.55
Control Group (*n*=37)	8.22	2.74	34.81	8.58	20.31*	3.34

Note: *Statistically significant (significance defined as $p < .05$).

The results are shown in Table VI. From Table VI, it can be seen that the improvements from pretest to posttest for both groups were statistically significant, ($t(36)=33.80$, $p<.05$; $t(36)=20.3$, $p<.05$; for strategy and control groups, respectively). The Cohen's *d* effect sizes (5.55 and 3.34 for strategy and control groups, respectively) pertaining to these improvements were very large.

C. The Effects of Problem-Solving Instruction on Strategy Use

In order to determine the groups' mean frequencies of problem solving strategy use, means and standard deviations were calculated for each sub-scales and total before and after the intervention. t-tests were conducted to determine if there were significantly differences between the means of the groups. Results were presented in Table VII.

The pretest results for both groups indicated no significant differences in total strategy use and sub-scales including understanding, planning, solving, checking and evaluating. Thus two groups were equal in the aspect of strategy use before the intervention.

As shown from Table VII, on the posttest, students in the strategy group scored significantly higher in all sub-scales and totally than those in control group, ($t(72)=5.24$, $p<.05$; $t(72)=2.98$, $p<.05$; $t(72)=5.41$, $p<.05$; $t(72)=5.86$, $p<.05$; $t(72)=6.48$, $p<.05$; for understanding, planning, solving, checking and evaluating, and total, respectively).

Paired samples t-tests were used to test the differences between the pretest and posttest strategy measures for the strategy and control groups (see Table VIII). Results showed that the improvements from pretest to posttest for strategy group were statistically significant ($t(36)=14.55$, $p<.05$; $t(36)=9.90$, $p<.05$; $t(36)=9.23$, $p<.05$; $t(36)=7.78$, $p<.05$; $t(36)=20.55$, $p<.05$). Effect sizes for each sub-scale and total were computed. Using Cohen's [28] criteria, these values were very large, ranging from 1.28 to 3.38.

IV. DISCUSSION

The results of this study revealed that instruction of problem-solving strategies was effective for enhancing physics achievement, problem solving performance and strategy use. The first result of the study is consistent with the findings of problem solving instruction research in different subject matters at different grade level, from secondary to university.

Being effective of the strategy instruction on increasing the students' achievements on physics course supports various research findings which determine that the strategy instruction increased the success in different education levels and in different subject matters. For instance, in physics, in college level Foster [24]; and in first-year college level Ghavami [29] have found in their research which they did related to physics principles and application of them in college level that strategy instruction was effective on physics course achievement or conceptual understanding; and in eight grade on earth science achievement [30], and in adolescents with learning disabilities on mathematics [31].

In this study, both groups showed significant improvements from pretest to posttest. As the effect sizes of the instruction given to both groups were compared, it was seen that both instruction was effective on increasing the students' achievement; however, the effect size of the instruction applied on the strategy group (Cohen's *d*=3,24) was higher than the effect size of the instruction applied on the control group (Cohen's *d*=2,09). Although being the instruction applied on the control group also effective on increasing the students' achievement was an expected result of the research; in this context it may be commented that the students in the control group may have unconsciously developed their problem solving skills in order to pass the course and/or get better course grades. Because, during the research, it was observed that the students in the control group also participated voluntarily into problem solving process substantially, and they were eager to solve the problems, and more ambitious than those in the strategy group in passing the class.

And being the instruction applied on the strategy group more effective than the instruction applied on the control group is a natural result of the strategy instruction. In classroom observations, it was observed that the students in strategy group reviewed the learning materials in order to solve the problems, asked questions to instructor who execute the lecture, and requested help. By means of the problem solving activities, active participating of the students to the problem solving instructions was obtained. Problem solving activities required a student to use previously learned knowledge to solve a problem and identify their own learning deficiencies; and the environments which can maintain them to realize their learning deficiencies were obtained. Hence, using an explicit problem-solving instruction can help students' achievement more than traditional problem solving exercises.

Having positive effect of the strategy instruction on problem solving performance supports various research findings which determine that the strategy instruction increased the performance in physics and in science (5, 6, 7, 19, 21, 23, 32, 33, 34, 35] had come to this conclusion that strategy instruction was effective on problem solving performance. In chemistry Sutherland [36]; Jeon, Huffman and Noh [37]; in mathematics, Montague and Bos [27]; Montague [38]; Montague, Warger and Morgan [39]; Schurter [40] obtained similar findings in their research.

As the problem solving sheets collected from the students at the end of the problem solving session were examined, it was determined that all of the students had participated into these activities, and as the research progressed, there was an improvement in usage of problem solving strategy. The subjects in the strategy group displayed minimal knowledge of problem solving strategies on the pre-intervention interviews, but showed considerable improvement in such knowledge in the following treatments.

In the study, both groups showed significant improvements from pre to post performance measures. Students who received strategy instruction were significantly more successful in the problem solving tasks ($p<.05$) than students in control group. As the effect sizes of the problem solving activities done in both groups were compared, it was seen that both instruction was effective on increasing performance; however, the effect size of the instruction applied on the strategy group (Cohen's d=5.55) was higher than the effect size of the instruction applied on the control group (Cohen's d=3.34). There were major differences between both groups in their performances on the PSPT.

These differences appeared in the number and the quality of problems each group solved. Strictly speaking, students in the strategy group performed better than those in the control group on all dimensions of problem solving process. This result of the study might be due to the fact that problem solving instruction increased students' awareness of their problem-solving process knowledge and skills. From that point, we can say that using a problem-solving instruction could help students' problem-solving performance more than traditional problem-solving tasks (exercises).

Having positive effect of the problem solving strategy instruction on strategy usage was an expected result of the research; and it has consistency with the problem solving performance result. As the problem solving literature was reviewed, no research where problem solving strategy usage was investigated by scale in physics area had been encountered. The research done in physics area was focussed on to determining the problem solving skills by open-ended problems and coding rubrics. It was determined that scale usage was widespread only in following areas such as health sciences (medicine, nursing…), psychology, etc.

To sum up, the strategy group showed important gains in relation to physics achievement, problem solving performance and strategy use.

V. IMPLICATIONS

This study provides some evidences of the effects of using problem solving instruction on students' physics achievement, problem solving performance and strategy use. In comparison, explicit problem solving instruction was more effective in developing all aforementioned characteristics than traditional instruction. Explicit instruction fosters these student learning outcomes by engaging students actively in solving problems and becoming aware of every phases in this complex process. On the basis of findings, it is strongly recommended that physics instructors should use explicit problem solving instruction in their lessons to develop students' problem solving performance and the related outcomes such as course achievement. Further research is needed in different educational settings to determine the effects of strategy instruction on the affective learning outcomes (e.g. interests, attitudes and motivation).

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TABLE VII. Comparisons between strategy and control groups for PSSS pretest and posttest.

Sub-scales	*Measure*	*Groups*	*M*	*SD*	*df*	*t-value*	*p-value*
Understanding	Pretest	SG	48.22	6.64	72	.93	.35
		CG	46.67	7.59			
	Posttest	SG	55.35	6.27	72	5.24*	.00
		CG	46.84	7.62			
Planning	Pretest	SG	45.54	7.64	72	1.21	.23
		CG	43.54	6.47			
	Posttest	SG	48.78	7.97	72	2.98*	.01
		CG	43.70	6.60			
Solving	Pretest	SG	11.27	2.46	72	0.75	.46
		CG	11.65	1.84			
	Posttest	SG	14.13	2.07	72	5.41*	.00
		CG	11.62	1.92			
Checking and Evaluating	Pretest	SG	9.02	1.74	72	0.54	.59
		CG	8.78	2.14			
	Posttest	SG	12.48	2.98	72	5.86*	.00
		CG	8.84	2.33			
Total	Pretest	SG	114.05	13.65	72	1.13	.26
		CG	110.65	12.20			
	Posttest	SG	130.75	13.72	72	6.48*	.00
		CG	111.00	12.47			

Note: SG=strategy group (*n*=37); CG=control group (*n*=37).
*Statistically significant (significance defined as $p < .05$).

TABLE VIII. PSSS pretest and posttest comparison for the strategy and control groups.

		Pretest		*Posttest*			
Sub-scales	*Groups*	*M*	*SD*	*M*	*SD*	*t-value*	*Cohen's d*
Understanding	SG (*n*=37)	48.22	6.64	55.35	6.27	14.55*	2.39
	CG (*n*=37)	46.67	7.59	46.84	7.62	1.23	.20
Planning	SG (*n*=37)	45.54	7.64	48.78	7.97	9.90*	1.63
	CG (*n*=37)	43.54	6.47	43.70	6.59	1.53	.25
Solving	SG (*n*=37)	11.27	2.46	14.13	2.07	9.23*	1.52
	CG (*n*=37)	11.65	1.84	11.62	1.92	.22	.03
Checking and Evaluating	SG (*n*=37)	9.02	1.74	12.48	2.98	7.78*	1.28
	CG (*n*=37)	8.78	2.14	8.84	2.33	.46	.07
Total	SG (*n*=37)	114.05	13.65	130.75	13.72	20.55*	3.38
	CG (*n*=37)	110.65	12.20	111.00	12.47	1.43	.24

Note: SG=strategy group; CG=control group.
*Statistically significant (significance defined as $p < .05$).

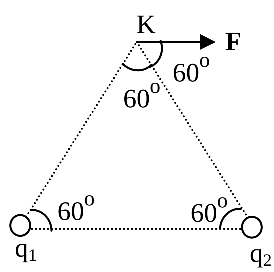
APPENDIX A

PHYSICS ACHIEVEMENT TEST (PAT)

Name, Surname: ....
Student Number: ....
Dear Students,

You are given a physics achievement test consisting of 34 questions below. Each of the questions is followed by five suggested answers. Please mark your answers on the answer sheet given to you. Mark only one answer to each question. Please use "Table of Information" in the end of the test paper. Total time given for this test is 90 minutes. At the end of the test, hand the test paper and answer sheet. Thank you for your participation. Good luck.

1.

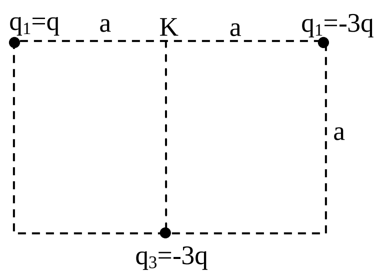


Which one/ones of the following expression(s) is(are) correct where the resultant force vector applied on the positive unit charge at point K by q_1 and q_2 charges was as in the figure above?

I. q_1 has positive charge, q_2 has negative charge.
II. Magnitude of the forces applied on the unit charge at point K by q_1 and q_2 charges are equal.
III. $q_1 = 2q_2$

(A) Only II (B) I and II (C) I and III
(D) II and III (E) I, II and III

2. q_1=q, q_2=-3q q_3=-3q charges were placed on the rectangle whose edge lengths are a, and 2a as in the figure below. If the magnitude of the electric field of q_1 charge at point K is E, then, how many E is the total electric field magnitude at point K ?



(A) E (B) 2E (C) 3E (D) 4E (E) 5E

3. Two plates having surface area of $20\text{x}10^{-4}$ m^2, and distance of $0.4\text{x}10^{-3}$ m between them are connected to a 120 V battery. How much charge flows to the plates in nC?

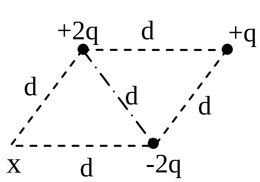
(A) 5.31 (B) 4.12 (C) 2.30
(D) 8.56 (E) 12

4. An air capacitor is connected to a battery, and charged, and after charged, it is disconnected from the battery, and then, connected to an ideal voltmeter. If a nonconductive material having higher dielectric constant is placed between its plates, then, which one/ones of the following(s) occur(s)?

I. Its capacity increases
II. Its energy increases
III. The potential difference between its ends increases
IV. Its charge does not change

(A) Only III (B) Only II (C) Only II
(D) I and IV (E) I,II, III and IV

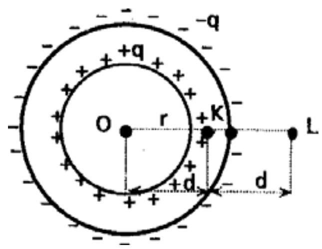
5.



Which one of the followings does the potential at point x generated by the charges placed as in the figure above equal to?

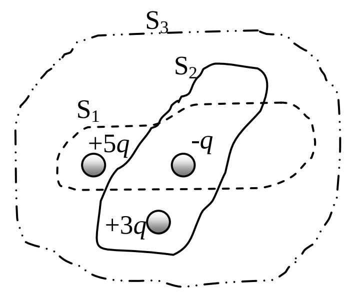
(A) $\sqrt{3}k\dfrac{q}{d}$ (B) $2k\dfrac{q}{d\sqrt{3}}$ (C) $k\dfrac{q}{d\sqrt{3}}$
(D) $k\dfrac{q}{d\sqrt{2}}$ (E) $k\dfrac{q}{2d}$

6. There is +q charge at the inner sphere, and -q charge at the outer sphere from the conductive empty spheres which were placed one inside the other in the figure on the right. If the magnitude of the electric field at point K is E, then, how many E is the electric field magnitude at point L?



(A) 1/3 (B) 1/2 (C) 1 (D) 2 (E) 0

7.



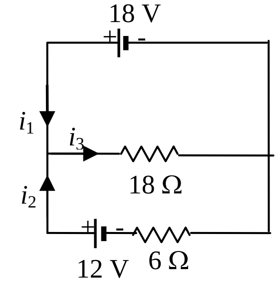
Three charges were given as in the figure above. What are the electric flux values passing through the closed surfaces S_1, S_2 and S_3?

	S1	S2	S3
(A)	$4q/\varepsilon_o$	$2q/\varepsilon_o$	$7q/\varepsilon_o$
(B)	$-q/\varepsilon_o$	$3q/\varepsilon_o$	$8q/\varepsilon_o$
(C)	$5q/\varepsilon_o$	$3q/\varepsilon_o$	0
(D)	0	$-3q/\varepsilon_o$	$5/\varepsilon_o$
(E)	$-3q/\varepsilon_o$	0	$7q/\varepsilon_o$

8. A point charge of – 8μC is located at the center of a sphere with a radius of 20 cm. What is the electric flux through the surface of this sphere in $N.m^2/C$?

(A) $9\text{x}10^5$ (B) $8\text{x}10^5$ (C) $2\text{x}\ 10^5$
(D) 10^5 (E) $6\text{x}\ 10^5$

9. Which of them is the concept defined as "Work done against electrical forces in order to bring a positive charge to a certain distance from infinity"?



(A) Electrical potential energy
(B) Electric potential
(C) Electric force
(D) Electric field

(E) Electric flux

10. Find i_1, i_2 and i_3 currents at the circuit in the figure. (The internal resistances of the batteries are neglected)

	i_1	i_2	i_3
(A)	2	-1	-1
(B)	1	1	2
(C)	1	2	1
(D)	2	-1	1
(E)	-1	2	1

11. A circular surface with a radius of 30 cm is turned to a position where the maximum flux was obtained in a regular electric field. At this position, the flux is measured as $5.4x10^4$ $N.m^2/C$. How many N/C is the magnitude of the electric field?

(A) 1.10^5 (B) 2.10^5 (C) 4.10^5

(D) 6.10^5 (E) 8.10^5

12. A proton is ejected to a regular electric field zone having $\vec{E} = -5x0^5\vec{i}$ N/C to +x direction. What is the acceleration of the proton (in terms of m/s^2)?

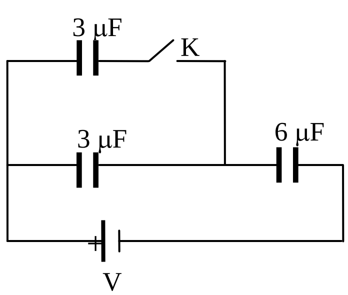
(A) $\vec{a} = -5x10^{13}\vec{i}$
(B) $\vec{a} = -2x10^{13}\vec{i}$
(C) $\vec{a} = +5x10^{13}\vec{i}$
(D) $\vec{a} = +1x10^{13}\vec{i}$
(E) $\vec{a} = -2x10^{13}\vec{i}$

13. Which one/ones of the followings are <u>not</u> the features of a conductor in an electrostatic equilibrium?
I. The electric field in a conductor is zero.
II. Excess charge is collected at the surface.
III. Distribution of the charges is regular, and independent of the geometry of the conductor.
IV. No charge exists within the conductor.

(A) Only II (B) Only III (C) Only IV

(D) I, II and III (E) III and IV

14.



If the charge of a capacitor with a capacity of 6 μF is q_1 when the switch K was open, and q_2 when the switch was closed, what is the ratio of q_1/q_2?
(A) 3 (B) 3/2 (C) 2/3 (D) 2 (E) 1

15. Among the electrical charged spheres K, L, M, N; K attracts L, and repels N, and M attracts N. According to this, which ones of the following spheres have the same charge sign?

(A) K and L, M and N
(B) K and M, L and N
(C) K and N, L and M
(D) L, M, N
(E) K, L, M

16.

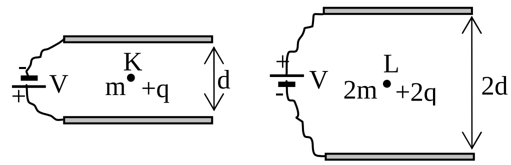
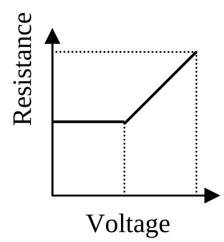


Figure 1 Figure 2

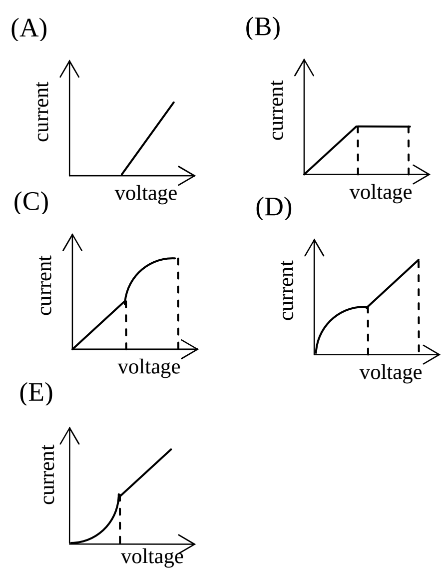
The resultant force affecting onto charged body K between the plates at the Figure 1 is zero.
According to this, how many mg is the resultant force affecting onto charged body L between the plates at the Figure 2? (g:gravitational acceleration)

(A) 1 (B) 2 (C) 3 (D) 4 (E) 5

17.



Which one of them is the current-voltage graph of the conductor whose resistance-voltage graph is as in the figure above?



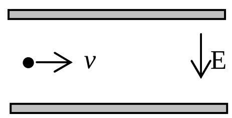
18. How many ohms is a resistance of a silver wire having a vertical cross section area of 0.4 mm^2 and a length of 40 m at

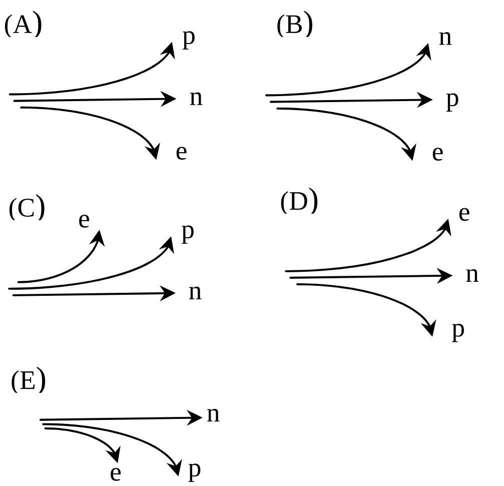
20 ºC temperature? (at 20 ºC, the resistivity of the silver is $\rho=1.6.10^{-8}$ Ω.m)

(A) 4 (B) 10 (C) 1.6 (D) 1.2 (E) 50

19. The electric field between parallel plates are downwards. If a proton (p), an electron (e) and a neutron (n) were ejected with a horizontal velocity of V as in the figure, how do their orbits become?

(The gravitational effect will be neglected)





20. Which one/ones of the following informations given for the electric field lines constituted by the standing charges are correct?

I. The lines must begin on positive charges and terminate on negative charges.

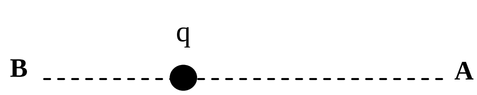
II. The electric field vector is tangent to the electric field line at each point.

III. E is small when the field lines are close together and large when they are far apart.

(A) Only I (B) Only II (C) Only III

(D) I and II (E) II and III

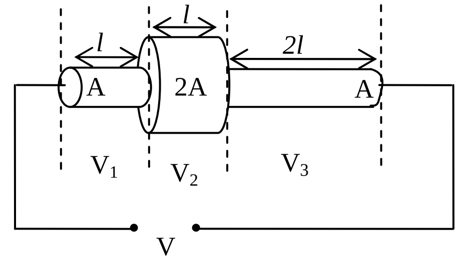
21. The charge value of a point charge is q=+1μC. Let's think a point A 2 m far from the charge, and a point B 1m far from the charge at the opposite direction. How many kilovolts is the potential difference V_A-V_B=?



(A) 2.34 (B)-6.3 (C) -4.5

(D) 8.78 (E) -7.4

22.



The lengths of the conductors made of same type of material and at the same temperature are *l*, *l*, *2l*, and their cross sections are A, 2A, A respectively.

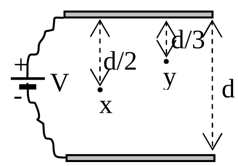
How is the correlation among the voltages V_1, V_2, V_3 occurred on each conductor?

(A) $V_1= V_2= V_3$ (B) $V_1> V_2= V_3$

(C) $V_3> V_2> V_1$ (D) $V_3> V_1> V_2$

(E) $V_3 =V_1> V_2$

23.



The electric field E between the plates at the figure above is regular. What is the difference between the potentials of the points x and y chosen between the plates (V_y- V_x)?

(A)-Ed/2 (B)-Ed/6 (C) Ed/3

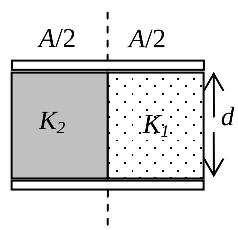
(D)-Ed/5 (E) Ed/4

24. The total electric flux passing through a cylinderic shape closed surface is $8.6\text{x}10^4$ N.m²/C. How many nC is the net electric charge within the cylinder?

(A) 860 (B) 124.2 (C) 570

(D) 213 (E) 761.1

25. The space between the plates of the parallel plate capacitor in the figure on the right was totally filled with two different dielectric materials. What is the capacity of the system in terms of the given variables? (A is the area of the plates, d is the distance between the plates, and, K_1 and K_2 are the dielectric constants of the materials)



(A) $\left(K_1+K_2\right)\varepsilon_o \frac{A}{d}$

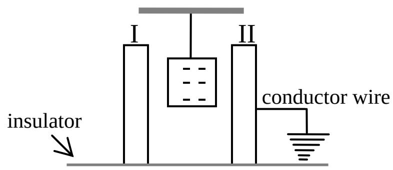
(B) $\left(\frac{K_1K_2}{K_1+K_2}\right)\varepsilon_o \frac{A}{2d}$

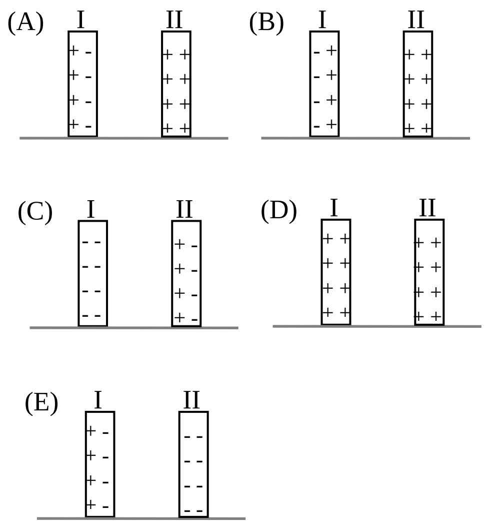
(C) $\left(K_1+K_2\right)\varepsilon_o \frac{A}{2d}$

(D) $\left(\frac{K_1K_2}{K_1+K_2}\right)\varepsilon_o \frac{A}{d}$

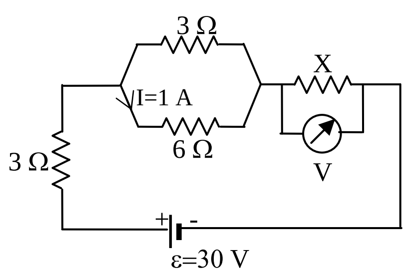
(E) $(K_1 + K_2)\varepsilon_o \dfrac{2A}{d}$

26. A negative (-) charged plate was hanged between the conductors I and II as in the figure below. If the conductive wire is cut first, and then the negative (-) charged plate is taken away, how would be the charge distribution on the conductors?





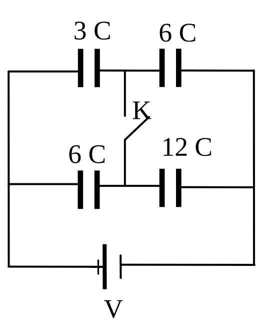
27.



According to the given values at the circuit in the figure above, how many volts does the voltmeter display? (The internal resistance of the generator was neglected.)

(A) 5 (B) 10 (C) 15 (D) 12 (E) 20

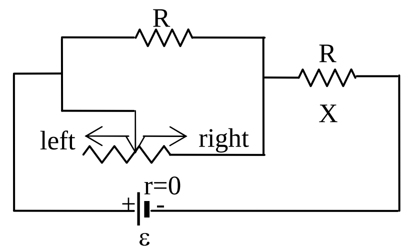
28.



At the circuit in the figure above, when the switch K is open, equivalent capacity becomes C_1, and when the switch K is closed, it becomes C_2. (The capacities are given as the times of C)
According to this, what is the ratio of C_1 / C_2?

(A) 1/3 (B) 1/2 (C) 1 (D) 2 (E) 3

29.



Which ones of the following processes should be performed in order to increase the current flowing through the resistance X at the circuit in the figure above?

I. Pulling the rheostat handle to the left
II. Pulling the rheostat handle to the right
III. Connecting a resistance R parallel to the resistance X

(A) Only I (B) Only II (C) Only III
(D) I and III (E) II and III

30.

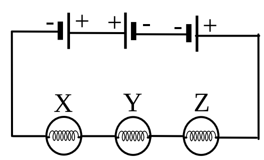


Figure 1

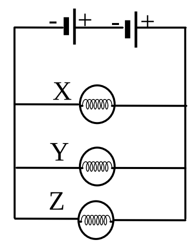


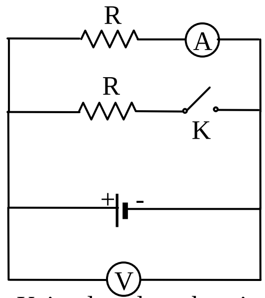
Figure 2

When the circuit formed by the identical generators at Figure 1 was connected as in the Figure 2, how do the brightnesses of the lamps change?
(A) X and Y lighten brighter, Z does not change
(B) The brightnesses of X, Y and Z do not change
(C) The brightnesses of X, Y and Z increase
(D) The brightnesses of X, Y and Z decrease
(E) Y and Z lighten brighter, X does not change

31. An electric heater is made of a nickel-chrome wire having a total resistance of 10 Ω, and 110 V potential difference was applied between its ends. How many watts does the electric heater consume?

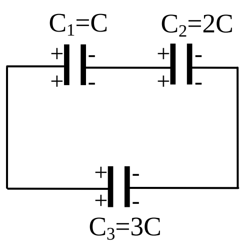
(A) 100 (B) 1500 (C) 1210
(D) 250 (E) 600

32.



If the switch K is closed at the circuit in the figure above formed by the identical resistances and generator whose internal resistance was neglected; how do the values displayed by the ampermeter A, and voltmeter V change as compared to the previous ones?
(A) A decreases, V does not change
(B) A increases, V does not change
(C) A and V increase
(D) A and V do not change
(E) A and V decrease

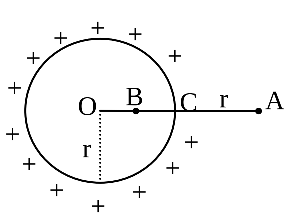
33.



Which ones of the followings are correct for the charged capacitors at the figure above?
I. $V_1 + V_2 = V_3$
II. $q_1 = q_2 < q_3$
III. $V_2 < V_1 < V_3$

(A) Only I (B) Only II (C) I and II
(D) II and III (E) I, II and III

34. In the figure on the right, a charged conductor sphere is given. What is the ratio of the potential differences at point A and B (V_A/V_B)? ($|OB| = |BC|$)



(A) 1 (B) 1/2 (C) 1/4 (D) 1/8 (E) 1/6

TABLE OF INFORMATION
Coulomb's constant $k=9x10^9$ N.m^2/C^2
Permittivity of free space $\varepsilon_o=8.85x10^{-12}$ C^2/N.m^2
$1\mu=10^{-6}$
$1n=10^{-9}$

APPENDIX B

Name, Surname: ....
Student Number: ....

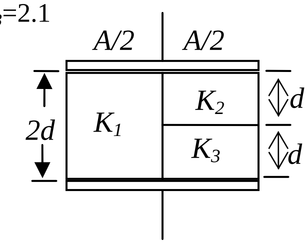
Dear Students,
This test was prepared to determine your-our valuable students'- problem solving performances. For the validity of this research, while solving the problems, specifying your all ideas and behaviours during the problem-solving period in written expressions in details has a special importance. Thank you, Good luck.

PROBLEM SOLVING PERFORMANCE TEST

Question 1: An electron moving parallel to the x axis has an initial velocity of 3.7 x 10^6 m/s at the origin. The velocity of the electron is reduced to 1.5 x 10^5 m/s at the point x=2 cm. Calculate the potential difference between the origin and the point x=2 cm. Which point is the higher potential?

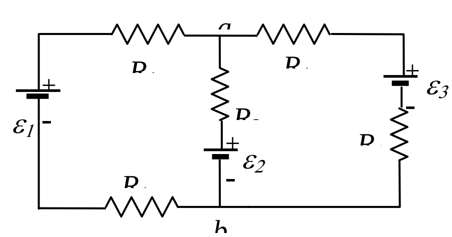
Question 2: Two charged concentric spheres have radii of 10.0 and 15.0 cm. The charge on the inner sphere is 4.00 x 10^{-8} C and that on the outer sphere is 2.00 x 10^{-8} C. Find the electric field (a) at r=12.0 cm and (b) at r=20.0 cm.

Question 3: A parallel-plate capacitor is constructed using three different dielectric materials, as shown in figure below. (a) Find the expression for the capacitance of the device in terms of the plate area A and d, K_1, K_2 and K_3. (b) Calculate the capacitance using the values A=1 cm^2, d=2 mm, K_1=4.9, K_2=5.6, and K_3=2.1



Question 4: A certain toaster has a heating element made of nichrome resistance wire. When first connected to a 120-V voltage source (and the wire is at a temperature of 20 ^{o}C) the initial current is 1.8 A, but the current begins to decrease as the resistive element heats up. When the toaster has reached its final operating temperature, the current has dropped to 1.53 A. (a) Find the power the toaster consumes when it is as its operating temperature. (b) What is the final temperature of the heating element?

Question 5: Calculate the current through each ideal battery in figure below. Assume that R_1=1.0 Ω, R_2=2.0 Ω, and ε_1=2.0 V, ε_2=ε_3=4.0 V. (b) Calculate V_a-V_b



APPENDIX C

PERFORMANCE ASSESSMENT RUBRIC

I. UNDERSTANDING THE PROBLEM
1. No understanding of the problem. (0 point)
2. Partial understanding of the problem. (1 point)
3. Adequate understanding of the problem. (2 points)
4. Superior understanding of the problem. (3 points)

II.PROBLEM SOLVING PATHWAY (ALGORITHM)
1. No suitable problem solving pathway. (0 point)
2. Inaccurate problem solving pathway. (1 point)
3. Adequate problem solving pathway. (2 points)
4. Superior problem solving pathway. (3 points)

III. CALCULATIONS
1. No calculations. (0 point)
2. Inaccurate calculations. (1 point)
3. Minor errors. (2 points)
4. Calculations are complete and right. (3 points)

IV. FINDING AND REPORTING OF SOLUTIONS
1. No response. (0 point)
2. Inaccurate response. (1 point)
3. Adequate reporting. (2 points)
4. Superior reporting. (3 points)

APPENDIX D

PROBLEM SOLVING STRATEGIES SCALE (PSSS)

Dear Students,

This scale was prepared to determine the strategies which you used while solving the physics problems, and how frequently you used them. For the validity of this research, specifying your actual ideas has a special importance. For each item below, please mark how frequently you did each activity by putting a check mark into the appropriate box. Thank you for participating in this study.

How frequently you do each activity below while solving physics problems?	Always	Frequently	Sometimes	Rarely	Never
1. I reread the problem.					
2. I try to comprehend the problem.					
3. I think of concept/concepts about the problem.					
4. I express the problem by my own sentences.					
5. I write the given variables about the problem.					
6. I express the problem by figures and diagrams.					
7. I review the rules and principles about the problem.					
8. I think of whether I encountered a similar problem before.					
9. I chart the given variables about the problem.					
10. I write the asked variables about the problem.					
11. I use the trial and error method in order to find a solution.					
12. I concrete abstract concepts about the problem.					
13. I think aloud the problem.					
14. I find possible solutions for the problem.					
15. I estimate the solution of the problem.					
16. I review the solution of the problem.					
17. I check the operation steps used in the solution of the problem.					
18. I divide the problems into sub problems.					
19. I write the remembered formulas related to the problem.					
20. I think of whether the answer given to the problem was logical.					
21. I table the given variables in the problem.					
22. I apply the first remembered solution.					
23. I visualize the problem by drawing.					
24. I think of the correlation among the given variables in the problem.					
25. I try different ways for the solution.					
26. I visualize the problem.					
27. I think of what about the problem was.					
28. I think of the different aspects of the problem from the similar problems.					
29. I categorize the information in the problem.					
30. I define the problem in more simple language.					
31. I underly the important points in the problem.					
32. I focus onto the solution of the problem.					
33. I interpret the results obtained from the problem.					
34. I think of the limitations in the problem.					
35. I plan for the solution.					

APPENDIX E

EXAMPLE PROBLEM SOLUTION

Dear Students,
As steps during the solving of each problem, please follow scripted directions as below.
Problem: Suppose that you wish to fabricate a uniform wire out of 1.00 g of copper. If the wire is to have a resistance of 0,500 Ω, and if all of the copper is to be used, what will be a) the length and b) the diameter of this wire? $(d_{Cu} = 8{,}93.10^3 kg/m^3, \rho_{Cu} = 1{,}7.10^{-8}\,\Omega.m)$ (Serway & Beichner, 2000, p. 863, problem 17)

STAGE 1: Understanding the problem

- Read and reread the problem carefully
- Determine the givens and desired quantities
  m= 1 g, R= 0,500 Ω   L =? 2r =?
- Identify the constraints in the problem
  Copper wire is ohmic substance
- Determine the significant information in the problem
  All of the copper is to be used
- Restate the problem by different forms (paraphrase the problem, drawing figure(s), diagram or graph(s) about the problem)

I have copper wire out of 1.00 g. If the wire is to have a resistance of 0,500 Ω, and if all of the copper is to be used, what will be the length and the diameter of it?

STAGE 2: Devising a plan

- Identify the principles, rules and laws about the problem

Physics principles: Mass and density relation and changing of resistance

Formulas: *Mass and density relation: $m = d.V$
*changing of resistance: $R = \rho.\frac{L}{A}$

- Determine the appropriate mathematical equations to solve the problem

$$m = d.V = d.A.L \quad A = \frac{m}{dL} \quad and \quad R = \frac{\rho L}{A} \Rightarrow$$

$$R = \frac{\rho L}{(\frac{m}{d.L})} = \frac{\rho d L^2}{m} \rightarrow$$

finally formul for desired first quantity $L = \sqrt{\frac{mR}{\rho d}}$

And finally formul for desired second quantity $\rightarrow V = \frac{m}{d} \Rightarrow \pi r^2 L = \frac{m}{d}$ *hence* $r = \sqrt{\frac{m}{\pi d L}}$

STAGE 3: Carrying out the plan

- Use the mathematical equations to solve the problem

$$L = \sqrt{\frac{mR}{\rho d}} = \sqrt{\frac{(1.10^{-3}\ kg).(0{,}5\ \Omega)}{(1{,}7.10^{-8}\ \Omega.m).(8{,}93.10^3 kg/m^3)}} = 1{,}81\ m$$

$$r = \sqrt{\frac{m}{\pi d L}} = \sqrt{\frac{(1.10^{-3} kg)}{3{,}14.(8{,}93.10^3 kg/m^3).(1{,}81 m)}} = 0{,}00014 m = 0{,}14 mm \Rightarrow$$

diameter of wire is $2r = 0{,}28\ mm$

STAGE 4: Looking back

- Checking the problem-solving pathway
- Checking the magnitude and the unit of the answer