Physics problem solving: Selecting more successful and less successful problem solvers

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***Abstract*—The purpose of this paper is to identify criteria in selecting more successful and less successful students in physics problem solving. The focus of the study is to see if more successful problem solvers are more metacognitive in their approaches and, if so, what this differences look like. This study consisted of 21 students, which all had a physics background at the university level. All of the respondents solved four physics problems in a physics pencil and paper test while talking aloud. In the meantime, each of the respondents were videotaped. Interviews were conducted right after the test. During the interview, the respondent's written answer to each of the problems were shown and the respondent were asked to discuss what they remember of their thinking when solving that problem. Written answers from physics task were marked according to the schema. As a conclusion, this study used performance as criteria in selecting more successful and less successful students in physics problem solving.**

Keywords—physics; problem solving; expert vs novice; more successful vs less successful; force and motion; circuit

I. INTRODUCTION

Studies of problem solving in physics started in the late 1970s. Problem solving has been defined in many ways for example: it has been interpreted as a *process* of moving towards a *goal* when the path is uncertain [1]; inferential steps that lead from a given state of affairs to a desired *goal* state [2]; an investigative task whereby the solver explores the solution path to reach a *goal* from given information [3]; a *process*, consists of a series of steps**,** and the problem solvers are involved in constructing the solution [4] and as a *process*, goal and basic skills [5].

Numerous physics problem solving models have been proposed [6-8]. The steps that were proposed by Adamovic and Hedden [6] are only successful when students are dealing with easy and straightforward questions. In fact, Adamovic and Hedden [6] stated this themselves, that the proposed model was successful only when students were dealing with traditional problems in physics. In all these models, it is expected that students' actions can be oriented to the direction of finding the right or best solution to a problem. Examples of steps that are taught to find the right solution are given in Table I below.

TABLE I. PROBLEM SOLVING STRATEGY

Activities/ Author(s)	1	2	3	4	5
[9]	-	Description	Planning	Implementation	Checking
[10]	Focus the problem	Describe the physics	Plan the solution	Execute the plan	Evaluate the answer
[6]	Read the problem	Write down what you know, Write down what you don't know-what is the problem asking for?	-	Find the correct equations to use, and write it down, Rewrite the equations with correct numbers in it and solve it	Write the answer down with the correct units

Metacognition include both, metacognitive knowledge and metacognitive experience or regulatory skills [11-13]. Metacognitive knowledge includes knowledge about variables of persons, tasks and strategies. Metacognitive experience includes metacognitive skills such as planning, monitoring and evaluating activities. According to Vos [14], metacognitive experiences influence the structuring and execution of cognitive tasks. Both metacognitive knowledge and experience/ regulatory skills are used to control one's cognition [13].

Flavel is one of the earliest psychologists that introduced the term of metacognition. According to Flavel [15] metacognition is "one's knowledge concerning one's own cognitive processes and products or anything related to them e.g., the learning relevant properties of information or data" (p.232). Flavel [15] also referred metacognition as "active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in the service of some concrete goal or objective"(p.232). Wilson and Clarke [16] summarised the meaning of metacognition by Flavel as individual awareness, evaluation and control of his or her own cognitive processes and strategies. In daily language, metacognition is described by Schoenfeld [17] as “reflections on cognition” or “thinking about your own thinking” (p. 189).

Metacognitive skills can help solve physics problem solving successfully [18, 19]. For example: Larkin [20] discovered that experts in physics differ from novices as they perform an initial qualitative analysis of the problems before using appropriate equations for the quantitative solution to the problems. Malone [19] demonstrated that students who received Modelling Instruction pedagogy are actively monitoring and regulating on their cognitive processes while solving problems. In addition, they routinely made more metacognitive statements compared to students that learnt by using conventional instruction especially in evaluating/checking as follows: approach taken; information used; appropriateness of the equations; and answer as well. Chi et al., [21] analysed self-explanation of good and poor problem solvers in physics as they studied and worked out examples. This study shows that actively and accurately monitoring their comprehension of the examples helps good problem solvers produced more self explanations compared to poor problem solvers. Ferguson-Hessler and de Jong [22] also discovered when studying a physics text, monitoring of their comprehension helps good problem solvers produce more self explanations and become better at detecting comprehension failures.

II. BACKGROUND OF THE PROBLEM

Malaysia puts the aspirations of becoming a top third in an international assessment such as TIMMS and PISA in 15 years [23]. This is due to the declined of international student achievement in TIMMS and PISA assessments in recent years.

The table below shows Malaysia’s science achievement in TIMSS since 1999. From the table, the average score of Malaysia in recent years 2011 is low compared to the average score TIMMS (see table I). Ranking of Malaysia also deteriorated over the years. Similar resulted happened on the PISA assessment.

TABLE II. MALAYSIA’S SCIENCS ACHIEVEMENT IN TIMSS SINCE 1999

	TIMMS 1999	*TIMSS 2003*	*TIMSS 2007*	*TIMSS 2011*
Malaysia ranking	22	20	21	32
Number of participating countries	38	50	49	45
Malaysia average score (A)	**492**	**510**	**471**	**426**
TIMSS scale average (B)	500	500	500	500

Source: Organization for Economic Cooperation and Development (OECD), Program for International Student Assessment (PISA), 2012.

The Program for International Student Assessment (PISA) is an international assessment that measures 15-year-old students' reading, mathematics and science literacy. Starting 2012, it also measures general problem solving and financial literacy as well. Table III shows Malaysia’s ranking score is lower than the average score in problem solving.

TABLE III. AVERAGE SCORE OF 15 YEAR OLD ON PISA PROBLEM SOLVING BY EDUCATION SYSTEM: 2012

Education system	**Average score**	**s.e.**	**Education system**	**Average score**	**s.e.**
OECD average (PS)	**500**	**0.7**			
Singapore	562	1.2	Denmark	497	2.9
Korea, Republic of	561	4.3	Portugal	494	3.6
Japan	552	3.1	Sweden	491	2.9
Macao-China	540	1.0	Russian Federation	489	3.4
Hong Kong-China	540	3.9	Slovak Republic	483	3.6
Shanghai-China	536	3.3	Poland	481	4.4
Chinese Taipei	534	2.9	Spain	477	4.1
Canada	526	2.4	Slovenia	476	1.5
Australia	523	1.9	Serbia, Republic of	473	3.1
Finland	523	2.3	Croatia	466	3.9
United Kingdom	517	4.2	Hungary	459	4.0
Estonia	515	2.5	Turkey	454	4.0
France	511	3.4	Israel	454	5.5
Netherlands	511	4.4	Chile	448	3.7
Italy	510	4.0	Cyprus	445	1.4
Czech Republic	509	3.1	Brazil	428	4.7
Germany	509	3.6	Malaysia	422	3.5
United States	508	3.9	United Arab Emirates	411	2.8
Belgium	508	2.5	Montenegro	407	1.2
Austria	506	3.6	Uruguay	403	3.5
Norway	503	3.3	Bulgaria	402	5.1
Ireland	498	3.2	Colombia	399	3.5

Source: Organization for Economic Cooperation and Development (OECD), Program for International Student Assessment (PISA), 2012.

If the problem persists, then aspiration of Malaysia’s government to achieve a developed nation status by the year 2020 cannot be achieved. Developed countries require a lot of expertise, especially in the fields of science, technology and engineering.

Since 1980, many studies have been done on the differences between experts and novices. However, little studies identified the criteria to select experts and novices subjects in problem solving. The differences between experts, novices and so called good and poor problem solvers are best described by Saul [24] who conducted an extensive review of the literature on this topic. According to Saul [24] experts refers to physics professors and physics graduate students while novices refers to physics undergraduate students. The so called “more successful” and “less successful” refers to students from undergraduate students. Saul’s definition has been supported by Simon & Simon [25], which they refers to expert as more experience and novice as less experience. Nevertheless, Malone [19] claimed good grades or performance are also basis criteria to be an experts in problem solving. For example, in order to select experts and novices, Heyworth [26] conducted problem solving test to students. Accordingly, those students that have good conceptual understanding and no procedural error in the test are selected as experts and those who made many procedural errors and poor conceptual understanding are selected as novices. Table I below demonstrates three prominent criterias that have been used by earlier researchers to select experts and novices in physics problem solving research. Previous research on novices and experts in problem solving (1978-2008) seem to shows that the criteria of selecting experts and novices in problem solving research are based on Table IV:

TABLE IV. CRITERIA TO SELECT EXPERT AND NOVICE SUBJECTS

Criteria (s)	Experts	Novices
Experiences [25, 27-32]	e.g: University Professors who had been involved in teaching and research in physics for at least 10 years [15].	e.g: Students who had completed only one semester of Classical Mechanics at the Introductory level [15].
Background knowledge [25, 26, 28, 31, 32]	e.g: 22 adults who had at least a bachelor's degree in physics [16].	e.g: 34 eleventh grade students who studied physics as their major subject [16].
Performances [26, 28, 30, 31, 33]	e.g: Those students who made no procedural errors and had good conceptual understanding [9].	e.g: Those students whose procedures were largely erroneous and had a poor conceptual understanding [9].

A. *Research Objectives*

The purpose of this paper is to identify criteria in selecting more successful and less successful students in physics problem solving?

B. *Research Questions*

Which criteria were used in selecting more successful and less successful students in physics problem solving?

III. METHODOLOGY

This study consisted of 21 students, which all had a physics background at the university level. The research participants were divided into two group; fieldwork 1 and fieldwork 2. 10 students were involved in the fieldwork 1 and the remaining 11 students in the fieldwork 2. The purpose of the fieldwork 1 was to check the difficulty of the physics task (Physics Problem Solving Achievement Test) and to refine the coding schemes or called as Coding Metacognitive in the Thinking Aloud Protocol (CMBTAP).

Students were informed of the main reason for the tests before the meeting for recruiting participants took place. The researcher handed over the group one sheet of paper containing an explanation of the research and the nature of what they are being asked to do through the class lecturer. The meeting was then arranged to meet them in a group which took about 20 minutes. Then the group was given a brief explanation of the study, and how many participants were needed for the fieldwork. All who consented to participate in the study leaved their details such as email or phone after the meeting. Date, time and venue were arranged which were convenient for the respondents to take part in the study. Prior to the start, the participants were required to read and sign the consent form.

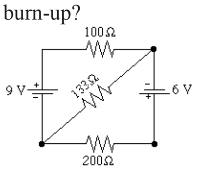
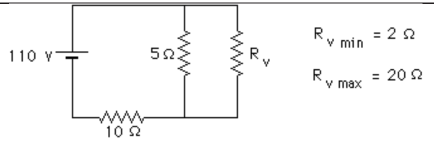
Students were informed that their identity were kept anonymous and results for the test in strictly confidential. If the students interested to know the result, the can contacted the researcher.

All of the respondents solved four physics problems in a physics pencil and paper test while talking aloud. The physics tasks were given name as Physics Problem Solving Achievement Test (PPSAT). The questions were given one by one to the respondents. The respondents were instructed to provide full solutions to each question on the test paper. No time limitation were given for the respondents to answer the questions, however if the respondents show impasse in their work, it was suggested that they move to the next question. In the meantime, each of the respondents were videotaped. Interviews were conducted right after the test. During the interview, the respondent's written answer to each of the problems were shown and the respondent were asked to discuss what they remember of their thinking when solving that problem.

Physics task or called Physics Problem Solving Achievement Test (PPSAT) in this study consisted of four questions of which two were drawn from the topics of mechanics and another two questions from electrical circuit. Two questions which were drawn from topics of mechanics were labeled as "lift problem" and "car on the hills problem" and two questions which were drawn from the topics of electrical circuit were labeled as "circuit inspection problem" and "toaster problem". The questions were adapted from University of Minnesota, Physics group [34]. The four questions in the physics task (PPSAT) were translated into Malay language by the researcher and were checked by language and content experts in Malaysia during the first fieldwork. In addition, the researcher also consulted three experts in physics content to check the answers and consulted one expert to check the marking schemes of the problems. Original questions were using United States context and unit. Therefore, the questions were modified to Malaysian context and to follow the International System of Unit (SI). Both, English and Malay languages were used in the PPSAT and participants were allowed to answer using the languages that they preferred. In conducting this study, participants were scheduled to do the task individually while "thinking aloud" in the present of researcher in the room.

The four problems that were drawn from the topics of mechanics and electrical circuits are as follows:

TABLE V. PROBLEMS FROM THE TOPIC OF MECHANICS AND ELECTRICAL

No.	Questions	Topics
1.	You have always been impressed by the speed of the lift at C22 at the Faculty of Science especially compared to the one in the C20 Physics Department. You wonder about the maximum acceleration for this lift during normal operation, so you decide to measure it by using your bathroom scale. While the lift is at rest on the ground floor, you get in, put down your scale, and stand on it. The scale reads 59 kg. You continue standing on the scale when the lift goes up, carefully watching the reading. During the trip to the 4th floor, the greatest scale reading was 82 kg.	Mechanics-Force and motion (Lift problem)
2.	While visiting a friend in Kuala Lumpur, you decide to drive around the city. You turn a corner and find yourself going up a steep hill. Suddenly a small boy runs out on the street chasing a ball. You slam on the brakes and skid to a stop, leaving a skid mark 15m long on the street. The boy calmly walks away, but a policeman watching from the sidewalks comes over and gives you a ticket for speeding. You are still shaking from the experience when he points out that the speed limit of this street is 40 km/h. After you recover your wits, you examine the situation more closely. You determine that the street makes an angle of 20^0 with the horizontal and that the coefficient of static friction between your tires and the street is 0.80. You also find that the coefficient of kinetic friction between your tires and the street is 0.60. Your car's information tells you that the mass of your car is 1570kg. You weigh 59 kg, and a witness tells you that the boy had a weight of about 27 kg and took 3.0 s to cross the 5m wide street. Will you fight the ticket in court?	Mechanics-Force and motion (car on the hill problem)
3.	As a student in laboratory management and safety, you have been given an assignment from your lecturer to inspect the circuit shown below. The resistors are rated at 0.5 Watts, which means they burn up if more than 0.5 Watts of power passes through them. Will the 100 ohm resistor in the circuit burn-up? 	Electricity-Circuit (circuit inspection problem)
4.	While trying to find the power ratings of your appliances you find their circuit diagrams. Looking them over, your friend believes there must be typographical error (printing error) in the circuit diagram of your toaster. The heating element that toasts the bread is listed as having a resistance of 5 ohms. A variable resistor, which is changed by a knob on front of the toaster, has a range of from 2 to 20 ohms. Your friend feels that an element with this resistance will not toast bread properly. Based on the circuit diagram, given below, you decide to calculate the maximum power output by the heating element.	Electricity-Circuit (toaster problem)
		

IV. FINDINGS AND DISCUSSION

Table VI are the scores obtained by each participating student on each of the four problems that consisted in this study:

TABLE VI. SCORE IN PHYSICS TASK

No.	Name	Questions			
		Mechanics		*Electricity*	
		1	*2*	*3*	*4*
1.	Adam	3/6	12/12	2/8	11/11
2.	Emma	6/6	9/12	3/8	5/11
3.	Ruby	3/6	6/12	8/8	5/11
4.	Isabelle	6/6	7/12	4/8	1/11
5.	Thalia	6/6	6/12	1/8	5/11
6.	Student a	6/6	5/12	2/8	5/11
7.	Student b	1/6	8/12	5/8	2/11
8.	Student c	2/6	5/12	5/8	4/11
9.	Student d	4/6	5/12	5/8	0/11
10.	Student e	5/6	4/12	4/8	0/11
11.	Student f	6/6	2/12	2/8	1/11
12.	Student g	3/6	3/12	0/8	4/11
13.	Student h	2/6	3/12	3/8	1/11
14	Student i	1/6	1/12	4/8	3/11
15.	James	2/6	3/12	3/8	1/11
16.	Student j	2/6	2/12	3/8	1/11
17.	Sophia	1/6	3/12	3/8	1/11
18.	Georgia	2/6	3/12	2/8	0/11
17.	Jack	1/6	2/12	1/8	1/11
20.	Student k	1/6	3/12	1/8	0/11
21.	Olivia	1/6	3/12	1/8	0/11

Then, the total score were calculated and changed to percentage (%). The highest score among participants was 75.7% and the lowest score was 13.5% (see Table VIII).

There are 5 levels of proficiency, excellent, good medium, weak and very weak (see table VII). In any performance test on Malaysian examination usually, those who achieved less than 40% are considered weak and very weak (Table VII).

TABLE VII. RANGE OF MARKS FOR DETERMINE THE LEVEL OF ACHIEVEMENT IN MALAYSIA EXAMINATION

Range of Marks (%)	Level of achievement
80-100	Excellent
60-79	Good
40-59	Moderate
20-39	Weak
0-19	Very Weak

Based on this preferences, 40% was chosen as the cut-off for differentiating between "more" and "less" successful. Participants were then labelled accordingly. It was anticipated that not all participants will fall neatly into one of these two groups. Respectively, eight participants were classified as "more successful" and 13 participants categorised as "less successful"(Table VIII).

TABLE VIII. CLASSIFICATION OF MORE SUCCESSFUL AND LESS SUCCESSFUL STUDENTS

No.	Name	Field-work	Scores (%)	Age	Gender	Rating
1.	Adam	2	75.7	23	M	More successful
2.	Emma	1	62.2	23	F	More successful
3.	Ruby	1	59.5	23	F	More successful
4.	Isabelle	2	48.6	20	F	More successful
5.	Thalia	1	48.6	23	F	More successful
6.	Student a	1	48.6	23	M	More successful
7.	Student b	1	43.2	23	F	More successful
8.	Student c	1	43.2	23	F	More successful
9.	Student d	2	37.8	23	M	Less successful
10.	Student e	2	35.1	21	F	Less successful
11.	Student f	2	29.7	23	F	Less successful
12.	Student g	2	27.0	23	F	Less successful
13.	Student h	1	24.3	23	F	Less successful
14.	James	1	24.3	25	M	Less successful
15.	Student i	2	24.3	20	F	Less successful
16.	Sophia	1	21.6	23	F	Less successful
17.	Student j	2	21.6	20	F	Less successful
18.	Georgia	2	18.9	24	F	Less successful
19.	Jack	1	13.5	20	M	Less successful
20.	Student k	2	13.5	20	F	Less successful
21.	Olivia	2	13.5	23	F	Less successful

The 10 students selected were assigned pseudonyms as Emma, Ruby, Adam, Isabelle, Thalia, James, Olivia, Georgia, Sophia and Jack while their real identities were kept anonymous. As shown in Table VII, Ruby, Emma and Isabelle were chosen from first fieldwork. They were classified as top rank participants from the scores of the first fieldwork. Adam and Thalia were chosen from fieldwork 2 and were classified as top rank participants as well from the scores of the second fieldwork. When the score of the participants from both fieldworks were merged together, Adam, Ruby, Emma, Isabelle, and Thalia emerged as the top five.

On the other hand, for "less successful" participants, James, Sophia and Jack were chosen from the first fieldwork. They were classified as the bottom participants from their score of the first fieldwork. Georgia and Olivia were chosen later and they were classified as the bottom rank participants as well as from the score of the second fieldwork.

The criteria for selecting the students also looked at respondent's cooperation during thinking aloud. Students who shows lacked of cooperation such as not trying to solve the problems and simply withdraw in answering the question also become criteria in selecting the students especially for less successful.

V. CONCLUSION

Criteria of selecting experts and novices in problem solving research in this study are based on performance in physics task. This study support study in the past by [26, 28, 30, 31, 33]

This study defined more successful as those students who achieved 40% or above and those who achieved lower than 40% categorized as "less successful".

It is also support study by Heyworth [26] which defined more successful as those who made no procedural errors and had good conceptual understanding and less successful as those students whose procedures were largely erroneous and had a poor conceptual understanding.

Apart from that, the criteria for selecting the students also looked at respondent's cooperation during thinking aloud. Students who shows lacked of cooperation such as not trying to solve the problems and simply withdraw in answering the question also become criteria in selecting the students especially for less successful.

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REFERENCES

[1] Martinez, M.E., *What Is Problem Solving?* The Phi Delta Kappan, 1998. **79**(8): p. 605-609.

[2] Barbey, A.K. and L.W. Barsalou, *Reasoning and problem solving: models*, in *Encyclopedia of neuroscience*, L. Squire, Editor. 2009, Academic Press: Oxford. p. 35-43.

[3] Dhillon, A.S., *Individual differences within problem-solving strategies used in physics.* Science Education, 1998. **82**(3): p. 379-405.

[4] Hollabaugh, M., *Physics problem solving in cooperative learning groups*, in *Faculty of the Graduate School*1995, University of Minnesota.

[5] Branca, N.A., *Problem solving in school mathematics*, in *Yearbook (National Council of Teachers of Mathematics)*, S. Krulik and R.E. Reys, Editors. 1980, National Council of Teachers of Mathematics: Reston, Va. p. xiv, 241 p.

[6] Adamovic, C. and C.J. Hedden, *Problem-solving skills.* The Science Teacher, 1997. **64**(6): p. 20-23.

[7] Heller, P. and H. Mark, *Teaching problem solving through cooperative grouping. Part 2: Designing*

problems and structuring groups. American Journal of Physics, 1992a. **60**(7): p. 637-644.
[8] Reif, F., *Teaching problem solving-A scientific approach.* The Physics Teacher, 1981. **19**(5): p. 310-316.
[9] Reif, F., J.H. Larkin, and G.C. Brackett, *Teaching general learning and problem-solving skills.* American Journal of Physics, 1976. **44**(3): p. 212-217.
[10] Heller, P., R. Keith, and S. Anderson, *Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving.* American Journal of Physics, 1992b. **60**(7): p. 627-636.
[11] Flavell, J.H., *Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry.* American Psychologist, 1979. **34**(10): p. 906-911.
[12] Livingston, J., *Metacognition: An overview*, 2003.
[13] Schraw, G., *Promoting general metacognitive awareness.* Instructional Science, 1998. **26**(1): p. 113-125.
[14] Vos, H., *Metacognition in Higher Education*, 2001, University of Twente: Enschede. p. 154.
[15] Flavell, J.H., *Metacognitive aspects of problem solving*, in *The nature of intelligence*, L.B. Resnick and University of Pittsburgh. Learning Research and Development Center., Editors. 1976, Lawrence Erlbaum Associates: Hillsdale, N.J. New York. p. x, 364 p.
[16] Wilson, J. and D. Clarke, *Towards the modelling of mathematical metacognition.* Mathematics Education Research Journal, 2004. **16**(2): p. 25-48.
[17] Schoenfeld, A.H., *What's all the fuss about metacognition?*, in *Cognitive Science and Mathematics Education*, A.H. Schoenfeld, Editor. 1987, Lawrence Erlbaum Associates, Inc., Publisher: New Jersey. p. 189-215.
[18] Phang, F.A., *The pattern of physics problem-solving from the perspective of metacognition*, 2009, University of Cambridge. p. 345.
[19] Malone, K.L., *A comparative study of the cognitive and metacognitive differences between modeling and non-modeling high school physics students*, in *Department of PsychologyCenter for Innovation in Learning*2006, Carnegie Mellon University: Pittsburgh, PA.
[20] Larkin, J.H., *Processing information for effective problem solving.* Engineering Education, 1979. **70**(3): p. 285-288.
[21] Chi, M.T.H., et al., *Self-explanations: How students study and use examples in learning to solve problems.* Cognitive Science, 1989. **13**(2): p. 145-182.
[22] Ferguson-Hessler, M.G.M. and T. de Jong, *Studying Physics Texts: Differences in Study Processes Between Good and Poor Performers* Cognition and Instruction, 1990. **7**(1): p. 41-54.
[23] Ministry of Education, *Malaysia Education Blueprint 2013-2025* Ministry of Education, Editor 2012: Putrajaya.
[24] Saul, J.M., *Beyond problem solving: Evaluating introductory physics courses through the hidden curriculum*, 1998, University of Maryland
[25] Simon, D.P. and H.A. Simon, *Individual Differences in Solving Physics Problems*, in *Children's thinking : what develops?*, R.S. Siegler, Editor. 1978, L. Erlbaum Associates ;: Hillsdale, N.J. New York. p. 325-348.
[26] Heyworth, R.M., *Procedural and Conceptual Knowledge of Expert and Novice Students for the Solving of a Basic Problem in Chemistry.* International Journal of Science Education, 1999. **21**(2): p. 195-211.
[27] Chi, M.T.H., P.J. Feltovich, and R. Glaser, *Categorization and representation of physics problems by experts and novices.* Cognitive Science: A Multidisciplinary Journal, 1981. **5**(2): p. 121 - 152.
[28] de Jong, T. and M.G.M. Ferguson-Hessler, *Cognitive structures of good and poor novice problem solvers in physics.* Journal of Educational Psychology, 1986. **78**(4): p. 279-288.
[29] Discenna, J., *A study of knowledge structure in physics*, 1998. p. 47.
[30] Hardiman, P.T. and et al., *The Relation between Problem Categorization and Problem Solving among Novices and Experts*, 1988, National Science Foundation, Washington, DC. p. 27.
[31] Kohl, P.B. and N.D. Finkelstein, *Patterns of multiple representation use by experts and novices during physics problem solving.* Physical Review Special Topics - Physics Education Research, 2008. **4**(1): p. 1-13.
[32] Snyder, J.L., *An investigation of the knowledge structures of experts, intermediates and novices in physics.* International Journal of Science Education, 2000. **22**(9): p. 979 - 992.
[33] Stavy, R. and et al., *Students' Problem-Solving in Mechanics: Preference of a Process Based Model*. 1991: Report: ED350151. 8pp. 1991.
[34] University of Minnesota. *Context Rich Problems On Line Archive*. 2009 [cited 2009 08 October]; Available from: http://groups.physics.umn.edu/physed/Research/CRP/on-lineArchive/ola.html.