EXPLORATION OF STUDENTS' PHYSICS PROBLEM SOLVING APPROACH USING LATERAL SCAFFOLDING TECHNIQUE

Balasubrahmanya Hegde[1] & B. N. Meera[2]

[1]Department of Physics, ACE Creative Learning Pvt Ltd (India),

[2]Department of Physics, Bangalore University (India)

baluhegde@gmail.com, bnmeera@gmail.com

Inculcating general and domain specific problem solving skills has continued to hold the interest of researchers. In the context of problem solving in Physics, influencing factors are many and the interplay among them is complex thus rendering the understanding of the problem solving process hard. One way of attempting to understand this is to enable a student to navigate through a particular problem that shall allow the researcher to decipher at least a subset of the influencing factors. In this paper, we report the investigations of the reactions and responses to a Physics problem. During the problem solving process, lateral scaffoldings were provided. Which scaffolding does a learner use and when and how does he/she use them unearths influencing deterring factors. Analysis of the results suggest an instructional approach that may require a directed approach to the strengthening of skill sets and that when embedded in a well-designed Physics problem may develop robust problem solving skills.

INTRODUCTION

Education is the process by which an individual is encouraged and enabled to fully develop his or her potential; it may also serve the purpose of equipping the individual with what is necessary to be a productive member of society. Through teaching and learning, the individual acquires and develops domain knowledge and skills, which are the chief contributors for the development of students' problem solving abilities. The last two decades mark an important phase in the recognition of the transition from 'learning stage' to 'facilitate the learner stage' in the realm of problem solving in Physics (Madsen et al., 2015; Kontur et al., 2015; Barniol & Zavala, 2015; Zuza et al., 2015). In the present context, the literature cited discusses students' strategies for solving specific types of Physics problems (Larkin et al., 1981; van Heuvelen et al., 1991; Hake, 1998).

Research results indicate that students resort to hunting for the relevant equation as the important first step while solving a problem (Larkin, 1980; Frank, 1987; Mayer, 2003b). Not being able to recall the equation could be one of the major reasons for not solving the problem. It has also been observed that mathematical skill or the lack of it can be a major contributor not only in not being able to formulate a conceptual framework into a mathematical coherent structure, but also in not being able to reach the end of the solution while solving a problem (Leonard, Dufresne & Mestre, 1996; Hu & Rebello, 2014; Pretz et al., 2003). The inability of a student in translating verbal information into a coherent conceptual framework can be a major deterrent in reaching the said goal (Bunce & Heikkinen, 1986; Larkin & Reif, 1979; McDermott & Larkin, 1978; Singh, 2007; Polya, 1957). This issue gets compounded when the problem involves usage of Physics from different domains (Larkin et al., 1980; Cohen et al., 2000; Frank et al., 1987). Our own research substantiates these observations (Hegde & Meera, 2012; Hegde & Meera, 2011). Another aspect investigated by researchers in this field is the efficacies of an attempt by students to solve a

Physics problem in a group (Heller et al., 1992). It is in this context that we investigated the role of some of these issues in Physics problem solving by contriving the problem discussed below.

METHODOLOGY

In our study, we have adopted a two phase approach. We have obtained and analysed responses to Physics problems designed in Multiple Choice Question (MCQ) format and followed it up with semi-structured interviews to probe in detail the students' Physics problem solving methodologies. Three hundred students from undergraduate level were presented with a set of Physics problems in the MCQ format. Options for each question were designed with clear objectives. The students' responses were analysed. In this paper, we discuss the results of investigation of a selected representative problem. The responses to the MCQ test provide us with pointers that have been used in the design of interview protocol. The design of the interview protocol is the critical aspect of this study. The interview protocol is designed with appropriate scaffoldings so as to bring out the microstructure of their knowledge representations. The interview stage involves validation interview as the first step which serves the purpose of identifying whether a question conveys the meaning the interviewer intends to present to the student. Based on these inputs, the questions were reformulated wherever necessary and the scaffoldings were fine-tuned. These processes laid a foundation for the data interviews. Each student has been interviewed in a specially set up studio. We have interviewed ten students with this problem. The interviews were recorded using a video camera and electronic writing pad. Scaffoldings were given to ensure progression towards solution to the problem. The recordings have been transcribed and analyzed.

The students who participated in the study are in the age group of nineteen to twenty one years and are students of an undergraduate program. All the students studied Physics as one of their subjects. The problems presented ensured that the students had received formal class room instruction on the relevant topics.

Design Considerations for the Question

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic $\gamma = \left(\frac{7}{5}\right)$ gas at the same temperature 300 K. The piston of A is free to move, whereas that of B is fixed. The same amount of heat is supplied to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

For the solution of this problem, the following aspects of Physics learning are intrinsically relevant.

- Interpretation of 'piston is free to move' and 'piston is fixed'.

More often than not, we express the language of Physics and Physics instruction in terms of colloquial representation. However, the question that needs to be addressed is about the acceptance of such a practice amongst the student community unless and otherwise conveyed properly. Does 'free to move' imply constant pressure and 'fixed' imply constant volume.

- Relating Q and ΔT through $Q = nC\Delta T$.

The mathematical connectivity between heat supplied and the temperature difference/rise appears in different contexts in heat and thermodynamics. The choice of appropriate equation is an important step in such a case.

- Relating C_P and C_V through $\gamma = \frac{C_P}{C_V}$.

An important hindrance to learning is attributed to the choice of a symbol which can represent different physical quantities in different contexts. In this case, γ is used to represent the ratio of specific heats; however the same symbol can stand for or gamma radiation or coefficient of cubical expansion or in fact for anything! The recognition of accepted symbols in a given context is an important way of bridging the conceptual platform and mathematical structure.

Stage 1 –Pilot Study

In the pilot study, the question was presented in the MCQ format, as given below.

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic $\gamma = \left(\frac{7}{5}\right)$ gas at the same temperature 300 K. The piston of A is free to move, whereas that of B is fixed. The same amount of heat is supplied to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

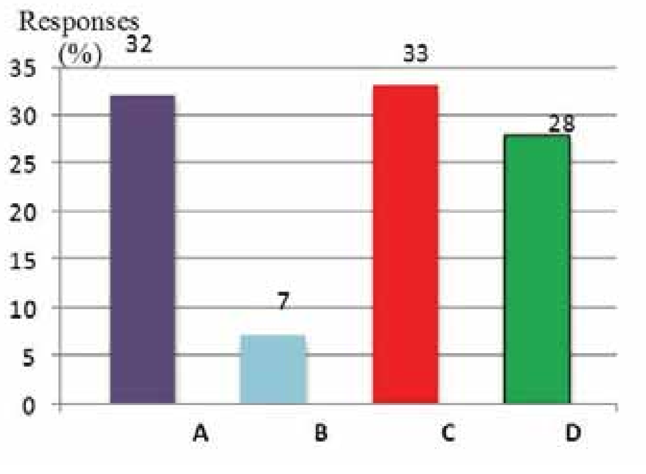

Figure 1: Students' responses

We observe that twenty eight percent of the students chose the correct option. The nature of distribution of the responses does not establish any clear dominant aspect of difficulty in solving this problem. The analysis of the MCQ responses presents us with several tasks. The important one is the necessity to investigate the difficulty in interpreting the colloquial statement into a coherent Physics concept. In addition to this, the role and mode of mathematical processing when multiple variables are involved also needs to be probed.

Stage 2 – Personal Interview

Design of Interview Protocol

The scaffoldings provided during the interview play an important role in the usefulness of interview proceeds. Research findings show that students rarely have a tendency to look for the underlying physical principles while solving a problem (Hegde & Meera, 2012; Hegde & Meera, 2011). Therefore, presenting the relevant physical principle to the problem solver is a weak scaffolding. The strong tendency for a student is to hunt for the relevant equation. Any help in this direction is, therefore, a strong scaffolding. In the design of the interview protocol, the weakest scaffolding was provided first. The categorization of a scaffolding as a weak scaffolding or a strong one is not really absolute. The sequencing order of the scaffoldings was generated taking into account the analysis of MCQ responses and also of validation interview results.

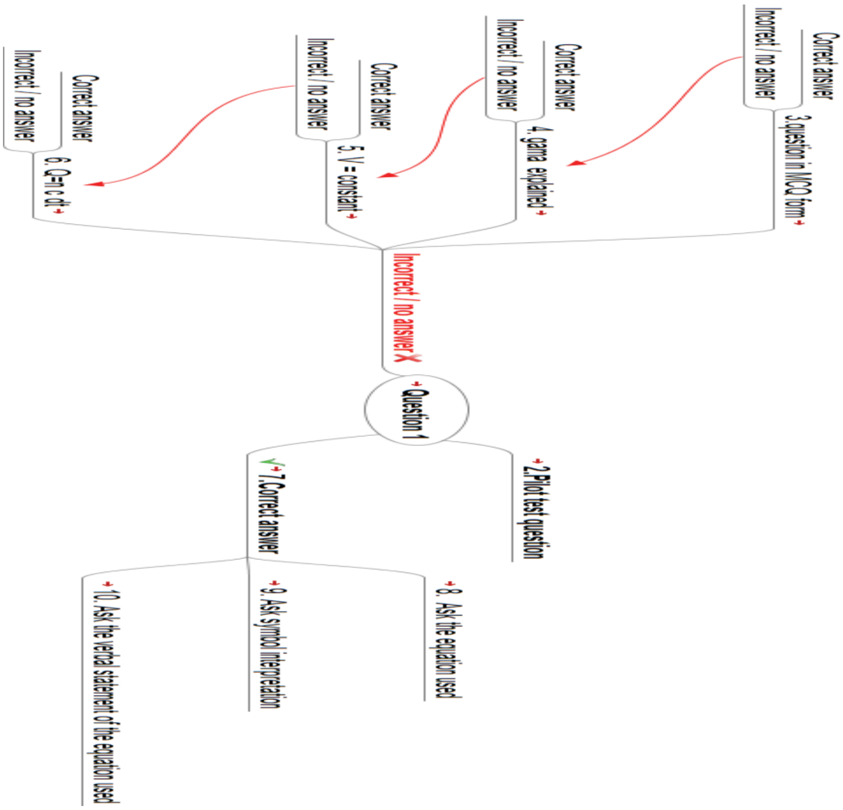

Figure 2: Mind map representation for scaffolding strategy management

As depicted above, the problem statements were structured in different versions to enable the student to use the corresponding scaffolding.

Version 1: Question in the Open Ended Format

To begin with, we presented the question in the open ended form as given below.

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic gas $\left(\gamma = \frac{7}{5}\right)$ at the same temperature. The piston of A is free to move, whereas that of B is fixed. The same amount of heat is supplied to the gas in each cylinder. The rise in temperature of the gas in A is 30 K. Calculate the rise in the temperature of the gas in B.

Of the ten students, one student could solve the problem successfully.

The students' responses revealed the lack of understanding between different relational aspects of specific heats of an ideal gas. The two chief relations between the specific heat at constant pressure C_p and that at constant volume C_v are $C_p - C_v = R$ and $\frac{C_p}{C_v} = \gamma$. These two equations govern most of the conceptual interconnections in the context of ideal gas laws and thermodynamics.

The excerpt below from one of the interviews highlights the lack of a coherent knowledge structure.

> "…the gas is diatomic, …however, the heat does not depend on that gamma…"

Such an observation from the student community is not rare. Clearly, a mismatch between the proper conceptual framework and the mental models carried by students needs to be addressed. Unless the link between the nature of the gas (read atomicity) and the heat absorbed is established during instruction, the required skill sets cannot be instilled.

Version 2: MCQ Format

For those students who could not solve the problem successfully, we rephrased the question in MCQ format.

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic gas $\left(\gamma = \frac{7}{5}\right)$ at the same temperature. The piston of A is free to move, whereas that of B is fixed. The same amount of heat is supplied to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of the gas in B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

Of the nine students who received this scaffolding, only one could use the MCQ format to solve successfully.

Version 3: Scaffolding Explaining γ

For those students who could not solve the problem successfully, we rephrased the question to include the definition of γ .

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic gas ($\gamma = \frac{C_P}{C_V} = \frac{7}{5}$) at the same temperature. The piston of A is free to move, whereas that of B is fixed. The same amount of heat is supplied to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of the gas in B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

Of the eight students who received this scaffolding, two students used this scaffolding to solve the problem successfully.

The meaning of physical processes in colloquial representations is one of the major bridges in establishing a robust and appropriate mental model in students. The following piece of interview transcript suggests the lack of connect between colloquial usage of physical processes.

> "…the piston is free to move in the first case, but it is not in the second case; how does it help?....I am not getting it…"

These requirements came from almost all the students who attempted this step. A conscious and deliberate effort is needed to establish a link between language of physical processes and their representations in terms of everyday life and can be of use in establishing a speedy problem solving ability in students.

Version 4: Scaffolding Explaining the Meaning and Consequence of Fixed Piston v/s Movable Piston

For those students who could not solve the problem successfully, we rephrased the question to include the meaning of 'piston is fixed' and 'the piston is movable'.

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic gas. The ratio of specific heats of a diatomic ideal gas is $\gamma = \frac{C_P}{C_V} = \frac{7}{5}$. Both the cylinders are at the same temperature. The piston of A is free to move (the pressure of the gas in A is constant), whereas that of B is fixed (the volume of the gas in B is constant). The same amount of heat is supplied to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of the gas in B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

Of the six students who received this scaffolding, two students used the scaffolding to solve successfully.

Version 5: Question with Maximum Impact Scaffolding i.e., Equation for Heat Absorbed Given

For those students who could not solve the problem successfully, we rephrased the question to include the equation connecting heat supplied to the change in temperature.

Two cylinders A and B fitted with light and smooth pistons contain equal amounts of an ideal diatomic gas. The ratio of specific heats of the ideal gas is $\gamma = \frac{C_P}{C_V} = \frac{7}{5}$. Both the cylinders are at the same temperature. The piston of A is free to move (the pressure of the gas in A is constant), whereas that of B is fixed (the volume of the gas in B is constant). The same amount of heat is supplied to the gas in each cylinder. The heat supplied during a thermodynamic process is given by $Q = nC\Delta T$. If the rise in temperature of the gas in A is 30 K, then the rise the temperature of the gas in B is

(A) 30 K (B) 18 K (C) 50 K (D) 42 K

Of the four students who received this scaffolding, three students could use the scaffolding to solve successfully.

The remaining one student had difficulty in bringing C_P and C_V into the mathematical formalism.

Equation hunting has been known to be an impediment in problem solving. However, given the equation in a slightly altered form – which eliminates the need for random equation hunting process —can a student build up on it and generate the equation needed becomes the most important question. In our research, we got no strong correlation to support the above said expectation. As one of the students said during the interview,

> "…you have given $Q = nC\Delta T$ But there are C_P and C_V .… How to connect them to temperature change?....."

This was one of the persistent questions from students. The mathematical skill to reconstruct the equations to suit the altered context is not a natural learning outcome; it needs a deliberate restructuring during instruction.

Exploration of strategies by those students who solved the problem correctly during individual interviews

We wanted to investigate not only the above said parameters, but also the approach by successful solvers. We wanted to investigate further by exploring the knowledge structure used for solving the problem. We began by exploring it with a question as given below:

> "Which equation is used in arriving at the answer?"

We ask this question because we hypothesize that a novice would approach a problem by the process of random equation hunting.

All the six students who received this question could answer it. As expected the equation for heat supplied in terms of specific heat capacity was the answer given by the students.

In the next step, we asked the students if he/she can identify the meaning of the symbols used.

We asked this equation because an equation in mathematics is a functional representation using symbols; in an equation in Physics, symbols represent physical quantities. In Physics a given symbol represents different physical quantities in different contexts (many to one transformation). Four students could answer it. However, for two students, ΔT meant the temperature difference (as in heat conduction) rather than temperature rise/fall.

In the next step, we asked the students if he/she can verbally state the physical law that is represented by this equation used while arriving at the answer.

We are interested in knowing the students approach to translate the mathematical equation into the statement of a physical law. The students could translate the mathematical equation into the statement of a physical law. The response of three students was

> "…heat is proportional to temperature change…."

In this problem, the temperature rise depends on the external conditions under which heat is supplied for the same amount of heat supplied. This issue remained unexpressed in the knowledge structure carried by students.

RESULTS AND DISCUSSIONS

The investigations reveal a methodology for examining the parameters which act as deterrents while solving a Physics problem. The existing and practiced instructional strategies often concentrate on building a conceptual framework along with the relevant mathematical rigor. However, often a student fails to construct his/her ideas beyond definitions and statements of laws which get exemplified in the context of problem solving. This investigation probes in detail the microstructure of student thought processes in the course of problem solving. The semi-structured interviews along with appropriately designed scaffoldings bring out the exact nature of the difficulties which otherwise do not get exposed. These lead us to the following conclusions.

As a first step in problem solving, it is logical to identify the physical principle applicable to the situation. However, the weak association of students' conceptual framework of the physical principles acts as a major deterrent in problem solving. Most often than not, the physical terms in the problem statement act as a trigger for the search of an equation and the inability to do so may hinder the problem solving completely. The weakness students' possess in connecting the symbols to the physical quantities can be attributed to a tendency to look at an equation in Physics not as a relation between physical quantities but merely as a mathematical equation. Another important parameter which can play a significant role in limiting the problem solving abilities is the lack of mathematical manipulation skills. This brings to the front a possible approach to strengthen problem solving skills which instead of solving numerous problems, addresses strengthening of skill sets. The problem for this need to be appropriately designed and directed effort to develop the necessary skills can then be the focus.

A factor whose influence cannot be undermined in the studies of this kind is the role of domain vulnerability of the problem solver in the problem context. A student who is already unclear of concepts in a domain of Physics may not get much help from scaffoldings. The scaffolding in such cases may not instigate the student towards a solution. Another limitation, here, is the non-uniqueness of scaffoldings, which cannot be sequenced. The absence of such a hierarchical structure may render a set of scaffoldings (generated for a question, designed for a learner) unusable in some other context. This being a possible limitation of the probing methodology, a learner independent but system dependent unique scaffoldings can hardly be designed. However, our investigations reveal similar constraints in learning even in the context of problems in other domains (Hegde & Meera, 2012; Hegde & Meera, 2011) suggesting the generality of the usefulness of the technique illustrated in this paper.

References

Barniol, P., & Zavala, G. (2015). Force, velocity, and work: The effects of different contexts on students' understanding of vector concepts using isomorphic problems. *Phys. Rev. ST Phys. Educ. Res. 10*, 020115.

Bunce, D. M., & Heikkinen, H. (1986). The effects of an explicit problem-solving approach on mathematical chemistry achievement. *Journal of Research in Science Teaching 23*(1), 11-20.

Cohen, J., Kennedy-Justice, M., Pai, S., Torres, C., Toomey, R., DePierro, E., & Garafalo, F. (2000). Encouraging meaningful quantitative problem solving. *Journal of Chemical Education, 77*, 1166-1173.

Frank, D. V., Baker, C. A., & Herron, J. D. (1987). Should students always use algorithms to solve problems? *Journal of Chemical Education, 64*, 514-515.

Hegde, B., & Meera, B. N. (2011). Multiple choice questions and interview as a combined tool for unravelling students' cognitive process in Physics. In S. Chunawala and M. Kharatmal (Eds.), *Proceedings of the Fourth epiSTEME 4 – International conference to review research on science, technology and mathematics education* (pp. 132-136). India: McMillan.

Hegde, B., & Meera, B. N. (2012). How do they solve it? An insight into the learner's approach to the mechanism of Physics problem solving. *Phys. Rev. ST Phys. Educ. Res. 8*, 010109.

Kontur, F. J., Harpe, K. L., & Terry, N. B. (2015). Benefits of completing homework for students with different aptitudes in an introductory electricity and magnetism course. *Phys. Rev. ST Phys. Educ. Res. 11,* 010105.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six thousand-student survey of mechanics test data for introductory Physics courses. *American Journal of Physics, 66*, 64-74.

Heller, P., Keith, K., & 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.

Hu, D., & Rebello, N. S. (2014). Shifting college students' epistemological framing using hypothetical debate problems. *Phys. Rev. ST Phys. Educ. Res. 10*(1), 010117.

Larkin, J. (1981). Cognition of learning Physics. *American Journal of Physics, 49,* 534 - 541.

Larkin, J. H., & Reif, F. (1979). Understanding and teaching problem-solving in Physics. European *Journal of Science Education 1*(2), 191-203.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science 208*(4450), 1335-1342.

Leonard, W. J., Dufresne, R. J., & Mestre, J. P. (1996). Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems. *American Journal of Physics 64*(12), 1495-1503.

Madsen, A., McKagan, S. B., & Sayre, E. C. (2015). How Physics instruction impacts students' beliefs about learning Physics: A meta-analysis of 24 studies. *Phys. Rev. ST Phys. Educ. Res. 11*, 010115.

Mayer, R. E. (2003b). *Learning and instruction*. New Jersey: Merrill Prentice Hall.

McDermott, J., & Larkin, J. H. (1978). Re-representing textbook physics problems. *Proceedings of the Second National Conference of the Canadian Society for Computational Studies of Intelligence.*

Polya, G. (1957). *How to solve it, 2nd ed.* NJ: Princeton University Press.

Pretz, J. E., Naples, A. J., & Sternberg, R. J. (2003). Recognizing, defining, and representing problems. *The Psychology of Problem Solving 30*(3).

Singh, C. (2007). Problem categorization in teaching and learning. Presented at the *American Association of Physics Teachers 2007 Summer Meeting.*

van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based strategies. *American Journal of Physics, 59*, 891-897.

Zuza, K., Almudí, J-M., Leniz, A., & Guisasola, J. (2015). Addressing students' difficulties with Faraday's law: A guided problem solving approach. *Phys. Rev. ST Phys. Educ. Res. 10,* 010122.