ESTEEM

ACADEMIC JOURNAL VOLUME 1. 2003 • ISSN: 1675-7939

Hadiah
UiTM
(PENANG)

Universiti Teknologi MARA Pulau Pinang

ESTEEM

Volume 1, December 2003

BHG. JURNAL & PENERBITAN

CONTENTS

The Effect of Physics Instruction on Conceptual Change and Problem-Solving In The Domain of Electric Circuits

Among High-Achiever College Students

Beh Kian Lim, Nazlinda Abdullah
Faculty Of Applied Science, University Technology Mara, 40450 Shah Alam, Malaysia

Abstract

This paper is based on a survey study (Beh and Abdullah, 2002) carried out to explore the effect of A-level instruction in physics on the formation of useful mental models among 164 high-achiever physics students for problem-solving using simple electric circuits as a context. The results revealed, among other things, that although majority of the students displayed good procedural understanding but among them many had not internalized any of the useful models for electric circuits of the parallel type in terms of current and voltage as presented implicitly in most physics textbooks. However, students who had mastered the practical knowledge of voltage and current achieved a higher rate of success in solving problems. After a year of A-level physics, students show significant improvement in all areas of practical knowledge concerning parallel circuits i.e. practical knowledge of current, voltage and resistance, ability to connect circuits, ability to discern parallel and series connections and ability to solve problems. It is concluded that designing teaching environments that will facilitate students in building internal representations of scientific ideas first before encouraging the repeated practice of procedures should be the emphasis in the science classrooms. A way to facilitate this for parallel circuits is by the explicit use of the two diagrammatical representations for parallel circuits as suggested in the paper.

Introduction

Modeling is the essence of scientific thinking. Models are both the methods and products of science (Harrison and Treagust, 1998). In learning situations, analogies, metaphors, and models are very often employed to illustrate complex processes or system (Kircher, 1984). In teaching electricity, for example, water analogies for current flow are frequently used. According to Tenny and Gentner (1984), one of the most powerful ways to understand a physical system is by an analogy/model. They suggested that learners' naÔve mental models are often formed around their own self –generated analogies. Gentner and Gentner (1983) showed that student errors on a test concerning electric circuitry depended upon the particular spontaneous analogy/model they were using. Is the finding by Gentner and Gentner (1983) applicable in the domain of simple electric circuits such as the parallel type (a domain which most students find troublesome)? This question forms the premise of this study.

In explaining resistive parallel circuitry, the normal focus in all the physics textbooks is to show the derivation of the formula for equivalent resistance $1/R=1/R_1+1/R_2$ without the explicit use of any model. However, implicitly the explanation implies that a resistive parallel circuit can be modeled in two different ways shown in Figure 1.

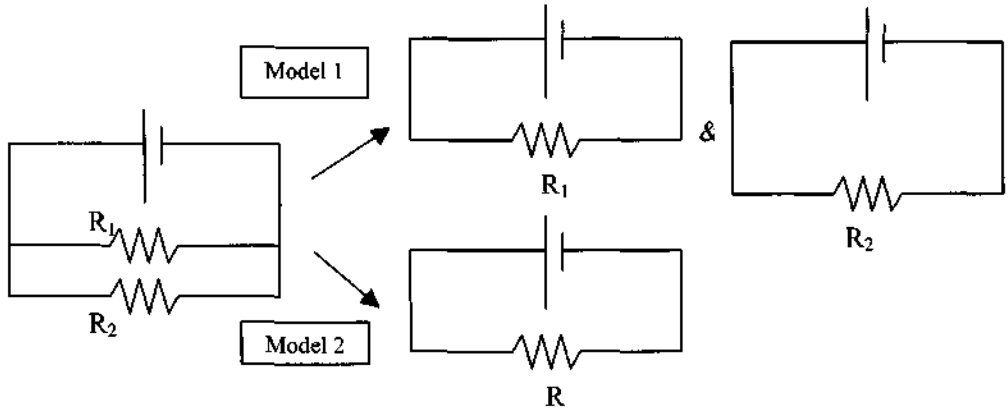


Figure 1: Two Models for a Parallel Circuit

Do high-achiever A-level students acquire these models after physics instruction about resistive parallel circuits?

Objectives of the Study

The study is an extension to the ones that have been implemented in UK(Beh, 1989), US (Beh, 1999), and Malaysia (Beh, 2000) by Beh. However, there is some variation in the objectives. The general objective for this study is to provide in depth information profile regarding **Malaysian high-achiever students' understanding of simple electric circuits after A-level instruction in Physics**. It is to ascertain whether this study would yield certain similar outcomes despite the obvious differences in terms of academic achievement, culture, and system of physics instruction as compared to three previous studies. Literature review revealed that comprehensive information specifically on high-achievers in the paradigm of constructivism that focuses on students' conceptions or beliefs regarding physical phenomena is lacking. The results will contribute to a more global and comprehensive view regarding student problems in understanding of the physic of electric circuits.
The study focuses mainly on answering the following two general questions:

1. Do high-achiever students after repeated learning about resistive parallel circuitry as a part of the study of electricity acquire any of the two 'models' (as shown in Figure 1) or any other models in particular to help them in understanding parallel circuits?
2. Does the learning of parallel circuitry in the A-level physics course in a typical Malaysian College result in any positive change in the high-achiever students' overall understanding of parallel electric circuits?

The Sample

Two groups of high-achiever students were involved for the actual study. They were:

- First semester of year 2001 A-level physics students who have studied parallel circuitry in schools (i.e. SPM level) prior to joining the university; and
- Third semester of year 2001 physics students who have studied parallel circuitry not only prior to joining the university but also in their second semester A-level physics course.

Student	Physics Grade				Total
	1	2	3	4	
Semester 1	41 (41.0%)	39 (39.0%)	19 (19.0%)	1 (1.0%)	100
Semester 3	15 (23.4%)	22 (34.4%)	22 (34.4%)	5 (7.8%)	64
Total	56 (34.1%)	61 (37.2%)	41 (25.0%)	6 (3.7%)	164

(Value)= percentage

Table 1. Profile Of Student Participated In The Survey.

Table 1 displays the number of students from the two groups who participated in the survey with respect to their physics grades obtained in their year 11 public examination (i.e., SPM). These 164 students volunteered to participate in the survey. The mean grade for semester 3 and semester 1 are 2.2 and 1.8 respectively. The difference in mean is found to be significant at 95% confidence.

Survey instrument

The questionnaire used for the survey was designed by the authors. It consisted of six major sections. Authors would discuss only questions in four sections (i.e., Section 2, Section 3, Section 4 and Section 6) which have direct bearing to the intent of this paper (see Appendix A for specific designations).

Section 2: practical knowledge of current

This section is designed to investigate the practical knowledge of current. Question (a) is to gauge student conception of Kirchhoff's First Law. Question (b) is to check the existence of 'sequential reasoning' among students as defined by Johsua and Dupin (1984). From the explanations offered, this question enables the investigator to gauge the use of Model 1 among students.

Section 3: practical knowledge of voltage in parallel circuit

This section is designed to investigate the practical knowledge of voltage. Questions (a) and (b) are used to check student ideas regarding voltages across resistors connected in parallel. In Question (c), capacitors are used in place of resistors to check whether students have the general understanding that any elements connected in parallel have the same voltage. This question enables the investigator to gauge the use of Model 1 by students via their explanations.

Section 4:practical knowledge of resistance

Question 2 of this section is designed to test the practical knowledge of resistance for a parallel circuit. From the explanations offered, Question 2 enables the investigator to gauge the use of Model 1 and Model 2 among students.

Section 6: mental model

This section is designed to seek the types of 'models' students have internalized regarding parallel circuits. There are two methods for solving the total electric current supplied by the battery in parallel circuits. One method is by obtaining first the current that flows through each of the two parallel resistors using the equation $I = V/R$. Kirchhoff's First Law ($I = I_1 + I_2$) is then applied to get the total current. It is inferred that students who use this method (called Method 1) possess an understanding of Model 1. However, students can obtain the value of total current from the battery by first calculating the resultant resistance by using the reciprocal formula. Ohm's Law is then applied to obtain the total current flowing from the battery. Students who use this method (called Method 2) are inferred to have acquired Model 2. The possession of Model 1 and Model 2 can only be further confirmed if students can answer Sections 2(a) and Section 2(b) (i.e., questions testing the conception of Kirchhoff's First Law), Section 3(a) and Section 3(b) (i.e., questions testing the conception of voltages across parallel resistors), and Question 2 of Section 4(a) correctly. This is because the two models are built upon the practical knowledge of current, voltage, and resistance as tested by respective sections. The four circuits in this section are drawn in four different formats. The intention is to see whether there is any relationship between surface features (i.e., the geometry of the drawing for circuits) and the methods employed by students.

The instrument used is the same as the one used by Beh (Beh,2000). Its reliability coefficient is r=0.969 for test-retest reliability and a= 0.7784 for Cronbach Alpha Reliability Coefficient. For validity of the instrument, content validity was established using a panel of experts.

Results and interpretations

To answer the two research questions, the results of the responses by students to Section 6 in relation to the other three sections (Section 2, Section 3, and Question 2 of Section 4) were used. Table 2 indicates the percentage of students who offered correct answers for the current supplied by the battery for the four parallel circuits, i.e., Circuits 6(a), 6(b), 6(c), and 6(d).

Student	**Per Cent of Correct Answer For Circuit**			
	6(a)	6(b)	6(c)	6(d)
Semester 1&3(n=164)	84.1	74.4	82.3	75.0
Semester 1(n=100)	75.0	66.0	74.0	65.0
Semester 3(n=64)	98.4	87.5	95.3	90.6
Difference Between 3 & 1	23.4	21.5	21.3	25.6

Table 2. Percentage of Students Calculating Source Current Correctly

Table 2 shows that generally, more than 70.0% of the students offered correct answers for all the circuits. Table 2 also reveals that the difference in percentage of students from Semester 3 and students from Semester 1 who calculated correctly for the current from the battery is large. The difference is substantial, ranging from 21.3% to 25.6%, with students from Semester 3 showing higher competency than students from Semester 1.

Circuit	Student	Per Cent of Method s Employed for Circuit Method			
		1	2	1&2	0
6(a)	Semester 1(n=100)	6.0	88.0	3.0	3.0
	Semester 3(n=64)	-	76.6	23.4	-
	Semester 1&3(n=164)	3.7	83.5	11.0	1.8
6(b)	Semester 1(n=100)	2.0	91.0	3.0	4.0
	Semester 3(n=64)	-	78.1	21.9	-
	Semester 1&3(n=164)	1.2	86.0	10.4	2.4
6(c)	Semester 1(n=100)	7.0	84.0	4.0	5.0
	Semester 3(n=64)	3.2	73.4	23.4	-
	Semester 1&3(n=164)	5.5	80.0	11.5	3.0
6(d)	Semester 1(n=100)	7.0	79.0	4.0	10.0
	Semester 3(n=64)	3.1	71.9	23.4	1.6
	Semester 1&3(n=164)	5.5	76.2	11.6	6.7

0: Not available

Table 3. Percentage of Students Employing Various Methods

Table 3 displays the methods employed by students for the 4 circuits (Circuit 6(a) to Circuit 6(d)). It reveals that Method 2 was the most favored method employed by students. Few students used Method 1. More than 10% (a few per cent for Semester 1 and >20% for Semester 3) of students Methods 1 & 2.

It may appear that most students have acquired Model 2 (since the results of this section indicated that a majority of the students used Method 2 only), a few students have acquired Model 1, and about 10% have acquired both the modes, 1 and 2. However, the poor performance of the students in Section B and in Section C indicated that most students did not exhibit a sound practical knowledge of current and voltage. It is hence concluded that most students have not really acquired either of the two models. The conclusion can be substantiated by the correlation of the total scores received by students in this section (Section 6) with the rest of the sections using Pearson r. The results indicate that the correlation between Section 6 and Section 2 (practical knowledge of current; r=0.186), between Section 6 and Section 3 (practical knowledge of voltage;r=0.228) and between Section 6 and Section 4 (practical knowledge of resistance; r=0.186) are low although significant. In actual fact the correlation between Section 6 and other sections are equally low (with Section 1, r=0.216; with Section 5, r=0.246).

The outcomes of the correlation analysis between sections and one of the findings in Section 3 (i.e., students tend to employ calculation strategies to obtain the values for voltage and do it blindly) lead to another conclusion, that is, students may be able to solve problems like those in Section 6 but they do so mechanically without much insight. This observation can be substantiated further by the results obtained displayed in cross-tabulation of student scores from Section 6 with that of student scores from Question (a) of Section 2 (practical knowledge of current) and Question (a) of Section 3 (practical knowledge of voltage

The cross-tabulation reveals the following:

- Thirty-one of the 44 students (70%) who had the prerequisite practical knowledge of current and voltage successfully answered the four questions in Section 6;
- None of the 8 student (0%) who had the prerequisite practical knowledge of voltage only has

successfully answered the four questions in Section 6;

- Forty-eight of the 82 student (58.5%) who had the prerequisite practical knowledge of current only successfully answered the four questions in Section 6;
- Thirteen of the 27 students (48%) who had no prerequisite practical knowledge of current and voltage successfully answered the four questions in Section 6.

The above results show that students who acquired the basic understanding of the practical knowledge of voltage and current obtained higher rates of success in solving the problems in Section 6 than those students who did not display such understanding. The results also show that 61 of the 120 students (50.8%) who lacked the prerequisite knowledge of current and voltage could correctly compute the source current for the four circuits correctly.

Conceptual and Procedural Understanding

Table 4 displays the mean scores for all the major sections. The mean scores have been scaled down to '1' for ease of comparison within sections in terms of level of difficulty. The mean for each section is a scaled down value in the range of zero to one. Values nearer to '1' indicate good performance by students and the values nearer to zero indicate poor performance by students.

	Mean Score of Semester		
Section	**1&3**	**1**	**3**
1:Meaning of Parallel	0.87	0.83	0.92
2:Practical Knowledge of Current	0.42	0.31	0.58
3:Practical Knowledge of Voltage	0.47	0.36	0.64
4:Practical Knowledge of Resistance	0.64	0.59	0.72
5:Practical Knowledge of Circuit Connection	0.72	0.67	0.81
6:Problem Solving/Mental model	0.78	0.69	0.92
Average	0.65	0.58	0.77

Table 4. Section Mean Score

When ranking is performed for the sections in terms of their mean scores, the following ascending order is obtained:$2 < 3 < 4 < 6 < 5 < 1$.The ranking shows that students were not successful in their level of conceptual understanding of the practical knowledge of current, voltage, and resistance. They were generally successful at identifying parallel circuits, connecting circuits, and computing (resistance using Ohm's law and source current)

Conclusions and implications for teaching

Understanding can be distinguished into two different kinds, the conceptual (or relational) and the procedural (or instrumental) (Skemp,1978; Hiebert and Carpenter, 1992). Conceptual understanding is rich in connection and it is 'knowing what to do and why'. Procedural understanding is knowledge of sequence of action and it is 'knowing rule without reason' such as computational skills (Skemp, 1978). These two views of understanding enable the following conclusions to be made:

- What students demonstrated in Section 2, Section 3, and Section 4 is their lack of the relational knowledge (which is termed as practical knowledge by the authors) of current, voltage, and resistance;
- What students demonstrated in Section 6 is the mastery of the procedural knowledge of Method 2;

- The two above findings are instrumental for the conclusion that generally students in the sample of this study have not internalized either of the models (Model 1 and Model 2) which have been implicitly suggested by the physics textbooks in their discussions of effective resistance for parallel circuits;
- According to Skemp (1978), procedural/instrumental understanding such as computational skill (which is devoid of conceptual understanding) should not be considered as understanding. Under this definition for understanding by Skemp, this study indicates that most students involved do not understand parallel circuits even though they have encountered this topic at least twice (at year 9 (PMR) and 11(SPM) for students from Semester 1 and at year 9, 11, and Semester 2 of college physics for students from Semester 3);

According to Hiebert and Carpenter (1992), both conceptual and procedural understanding are important since well–rehearsed procedures guide seemingly effortless solution of routine problems. However, they suggest that teaching environments should be designed to help students build internal representations of procedures that become part of larger conceptual networks before encouraging the repeated practice of procedures. The suggestion offered by Hiebert and Capenter, even though it is made primarily in the context of learning mathematics, is deemed appropriate for the learning of physics, especially for the topic of electric circuitry. The results revealed in this study probably occur because of the over emphasis on routine problem-solving while neglecting the building of the fundamental conceptual understanding in the teaching of electric circuits. It is observed that computing effective resistance is the main emphasis offered by most science textbooks designed for all levels of study (year 9 to college) pertaining to sections related to electric circuits. And, the science curriculum and experienced with physics by the students in this study were textbook-driven.

One of the many conclusions arrived in the study is that students who had mastered the practical knowledge of voltage and current would obtain a higher rate of success in problem-solving. The result is in support of the recommendation made by Hiebert and Carpenter (1992), i.e., teaching environments design to help students building internal representations of scientific ideas first before encouraging the repeated practice of procedures. A way to facilitate this for parallel circuits is by the explicit use of the two diagrammatical representations identified, i.e., Model 1 and Model 2 as shown in figure 1 as Bell et al.(1998) have substantiated with evidences that science contents, like any other cognitive outcomes, should be addressed explicitly

The conclusions arrived are very similar to the ones revealed by Beh using UK sample (Beh,1989, Millar and Beh, 1993), and USA sample (Beh,1999). This is probably because despite differences in both geographical and cultural settings, the instructional material and approaches used in the teaching of science are similar in nature, i.e. they belong to the traditional mode of 'content-driven' type.

As indicated in the introduction, this study on high-achiever is an extension of the previous study by Beh (Beh, 2000) using the same instrument on similar students but of mixed-group who obtained SPM physics-grade ranging from 3 to 8 with median at 6. Comparing the scores of the six sections of this study on high-achievers with that of the previous study (Beh, 2000) on mixed ability group. The scores for the high-achievers show similar trend with that obtained by the mixed-ability group i.e.:

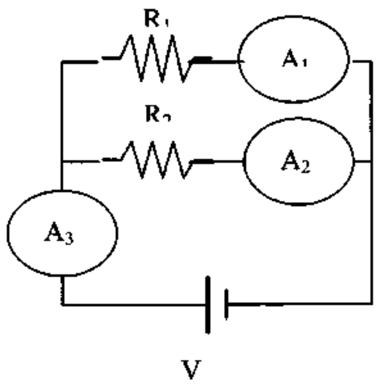
a. Both groups show high in computation skills, circuit identification, and in circuit connections but low in conceptual understanding pertaining to current, voltage, and resistance;
b. Both groups show that the achievement of Semester 3 is relative higher than semester 1.

The achievement by the high-achiever group is higher than that demonstrated by the mixed-ability group in all the six sections as revealed by the previous study by Beh (Beh, 2000), for example the average total scores for the students of high-achiever and the mixed-group are 0.65 and 0.61 respectively.

Since the topic of parallel electric circuitry is first formerly introduced to the Malaysia students at the PMR level, a similar study of this nature at PMR level is deemed appropriate in providing the developmental understanding of the Malaysian students in the various fundamental key concepts of electric circuitry.

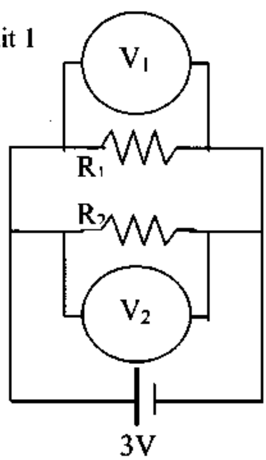
Appendix A

Circuit 1

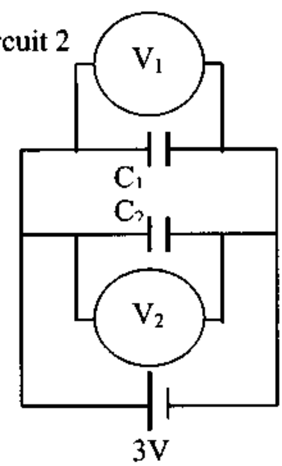


Section 2: practical knowledge of current

Circuit 1



Circuit 2



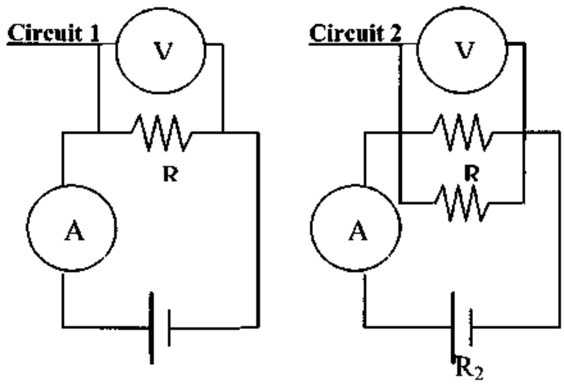
Section 3:practical knowledge of voltage in parallel circuit

In **Circuit 1**, the resisters R_1 and R_2 are of 1W and 2W respectively. V_1 and V_2 are voltmeters. The battery provides a voltage of 3V.
(Please provide explanations for your answers)

(a) What are the readings for the voltmeters V_1 and V_2?
(b) When the R_1 resistor is **disconnected** from the circuit, what readings would appear on the

voltmeters V_1 and V_2?

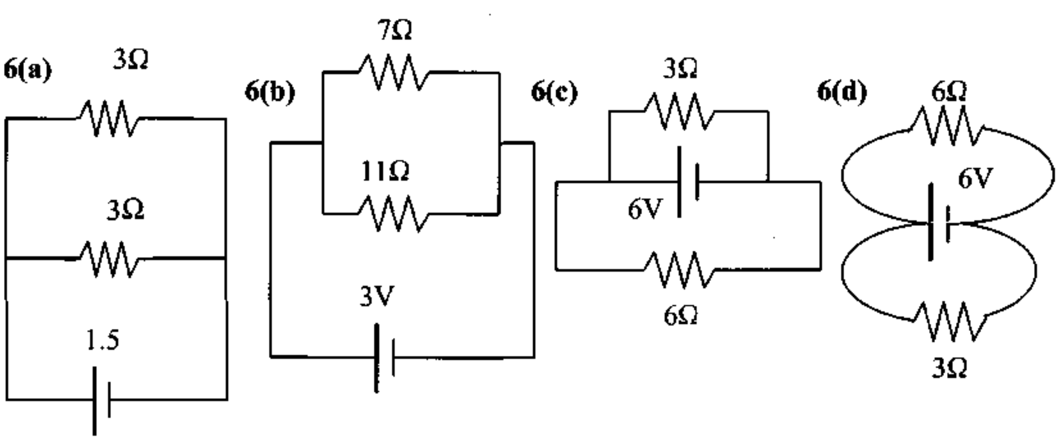
(c) R_1 and R_2 in Circuit 1 are replaced by capacitors C_1 and C_2 of the same capacitance (as shown **in Circuit 2**).What would be the readings of V_1 and V_2 ?



Section 4(a): practical knowledge of resistance

1. In **Circuit 1**, voltmeter V reads 5V and ammeter A reads 2.5A. What is the resistance of the resistor R?(show your calculations (given: Ohm's Law V=IR))
2. A resistor of the same resistance as R_2 is added to Circuit 1 as shown in **Circuit 2.**
   (i)How would this addition affect the reading of the ammeter?
   (ii) How would this addition affect the reading of the voltmeter?

What is the electric current supplied by the battery in each of the following circuits (circuits 6(a) to 6(d)).
*Please show how you work it out in the space provided under **Solution 1**.*
*If you can provide another method to solve each of the problems 6(a) to 6(d), please indicate this other method that you have in the space provided under **Solution 2**.*



Section 6:mental Model

References

Beh, K.L. and Abdullah, N. (2002) *The effect of physics instruction on conceptual change and problem-solving in the domain of electric circuits among high-achiever college students. Unpublished research report, Biro Penyelidikan dan Perundingan, Universiti Teknology Mara, 40450 Shah Alam, Malaysia.*

Beh, K.L.(2000) *An investigation of the effect of instruction in physics on the formation of mental models for problem-solving in the context of simple electric circuits. Unpublished Ph.D. thesis, The University of Iowa, Iowa, USA.*

Beh, K.L. (2000) *The Effect of Instruction in Physics on the Formation of Mental Models for Problem-solving in the Context of Simple Electric Circuits. Paper presented at Iowa Academy of Science Spring Conference, Hotel Fort Des Moine, Des Moine, Iowa. April 21-22, 2000.*

Beh, K .L .(1999) *Students' understanding of parallel electric circuits. Paper presented at 1999 Iowa Science Teachers Section Fall Conference, Iowa Academy of Science, Des Moines, Iowa, 14th October 1999.*

Beh, K . L. (1989). *An investigation of 5th form physics students' understanding of parallel electric circuits. Unpublished MS dissertation, University of York.*

Bell,R.L., Lederman,N.G., and Abd-El-Khalick, F.(1998) *Comments and criticism: implicit versus explicit nature of science instruction: an explicit response to Palmquist and Finley. Journal of Research in Science Teaching, 35(9),1057-1061*

Gentner, D., and Gentner, D. R. (1983) *Flowing waters or teaming crowds: mental models of electricity. In D. Gentner, and A.L. Steven (eds.),* Mental Models *(Hillsdale, New Jersey: Erlbaum), 55-67.*

Harrison, A. G., and Treagust, D. (1998) *Modelling in science lesson: are there better ways to learn with model?. School Science and Mathematics, 98(8), 420-429.*

Hiebert, J., and Carpenter,T. P.(1992) *Learning and teaching with understanding. In D. A. Grouws (ed.). Handbook of Research on Mathematics and Learning.(Macmillan), 65-97.*

Kircher, E. (1984). *Analogies for the electric circuit?. In R. Duit, W. Jung, and C. von Rhoneck (eds.), Aspects of Understanding Electricity (Kiel:IPN), 299-309.*

Millar, R. and Beh, K. L.(1993) *Students' understanding of voltage in simple parallel electric circuit. Int. J. Sci. Edu, 15(4), 351-361.*

Skemp, R. R. (1978) *Relational understanding and instrumental understanding. Arithmetic Teacher, November issue, 9-15.*

Tenney,Y. J. and Gentner, D. (1984) *What makes analogies accessible: experiments on the water-flow analogy for electricity. In R. Duit, W. Jung, and C. von Rhoneck (eds.), Aspects of Understanding Electricity (Kiel:IPN), 311-318.*