ICT AND CONSTRUCTIVIST STRATEGIES INSTRUCTION FOR SCIENCE AND MATHEMATICS EDUCATION

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Concept learning in science and mathematics had often times been taught based on assumptions of alternative concepts or even in some instances based on misconceptions. Some educational researchers favour a constructivist approach in teaching science and mathematics. The constructivist literature existing makes use of alternative conceptions as well as the mode of student learning and the roles of the instructor. This article intends to show that the so-called traditional instruction can be improved by amending the strategies used to teach a topic. In this study the topic selected was 'Electrolysis,' as it was considered 'difficult,' and the methodology used was a quasi-experimental research design. This study showed that it was possible to improve science or mathematics instruction in the traditional direct-instruction mode using alternative strategies.

INTRODUCTION

For too long, concept learning in Science and Mathematics had leaned onto the assumptions of alternative concepts, or in many instance misconceptions. For example Johnstone (2000) and de Jong (2000), the two leading Chemistry educators have differing viewpoints about instruction in chemistry. Both profess common inputs necessary to improve chemistry education, that is chemistry education is both domain specific as well as an empirically based model of learning. Johnstone refers to the "alternative frameworks" in chemistry education, while de Jong (2000) focuses more on "domain specific concepts". While re-synthesizing the arguments, Taber (2000) used the terms "the alternative conceptions movement" or more simply "constructivism" in chemistry education. In this he meant students construct their own knowledge of science concepts and therefore should be actively involved in the science lesson. Constructivist instruction provides an experiential base for learning science content and it is not about misconceptions or even simple communication errors that can be put right! It is mostly about how we "know" the contents during discourse. The advent of constructivist paradigms had in many ways impinged upon how we view information and communication technology (ICT) as a tool to advance these constructivist demands. For example, the *Internet* and *WWW* are seen as important and critical in providing the alternatives so much relevant to developing a constructivist learning environment. By breaking away from misconceptions it is hoped that methodologies, specifically *strategies*, will come to the fore in developing better instruction and learning. Is it failsafe?

Notice we might often be blaming the student / learner for any misfortune like "poor scientific skills," "poor logical reasoning from data provided," etc., as could be attested by the annual reports on student performances in the public examinations, e.g., those published by the Examination Board (*Lembaga Peperiksaan*) of the Ministry of Education Malaysia (*Kementerian Pelajaran Malaysia*). Thus one tends then to consign weak students' performances to their own inability to comprehend science and mathematics thereby perpetuating the sad story of weak scientific knowledge amongst student and even teachers. For example, only 19.6% of the emphasis given to thinking skills in KBSM (the new secondary school curriculum) had been understood and implemented by secondary school teachers, reported Shamsudin, Mod. Shah & Zaidah (1996). The question to ask is what form of implementation and relevant strategies one to take?

COGNITIVIST INTERPRETATIONS ABOUT CONSTRUCTIVIST APPROACHES TO LEARNING

If we were to look at the roots of constructivism, they have to come from cognitivist ideals but blended with more "personal" interpretation of concepts and their alternatives. For example, Taber (2000) continued with the suggestions teachers should be aware that:

1) to understand the new teaching, the students need to understand certain basic prerequisite ideas;
2) many of the students are likely to hold alternative conceptions about the topic, and have distorted understanding of the prerequisite ideas;
3) because students' existing ideas are integrated into their conceptual network, they may not easily change their thinking; and
4) as new knowledge is built on the foundations of existing beliefs, the teaching is likely to be misinterpreted;

Thus as a teacher, "my teaching" is likely to be ineffective, and many in the class will not learn the key ideas adequately. Unsurprisingly, Taber (2000) had cognitivist solutions to the dilemma explained. He proposed that the constructivist teacher should therefore:

i) start from where the students are (not where she would like them to be);
ii) start a new topic with the elicitation of existing knowledge; and

iii) plan lessons to reflect the elicited prior knowledge and understanding by

iv) reiterate missing prerequisite knowledge; and

v) explicitly challenging alternative conceptions (page 19)."

These exhortations sound very much cognitivist. It must be emphasized that a constructivist approach *does not* demean memorization as students must know or own certain facts in order to engage in the analysis required. Thus basics about a concept are non-negotiable necessities. These facts have personal relevance and meaning and from which students draw their experience and also in order for the teacher to help students shape their thoughts effectively (Lasley, Matczynski, & Rowley, 2002).

Schank & Kozma (2002) in describing the ChemSense learning environment in the context of actual use by high school students suggested the intersect of several theoretical approaches to learning, including collaborative project-based investigations, representational competence, knowledge building, and the design of chemistry curriculum. In fact according to them, chemistry learning requires students and instructors to collaborate in the investigation of chemical phenomena, collect data, build representations of these phenomena, and participate in scaffolded discourse to explain these phenomena in terms of underlying chemical mechanisms. This is similar in context to the ideas propounded by Jonassen (1999) about designing constructivist learning environments.

Taber (2000) summarized the contribution of constructivist literature on teaching in the following Figure 1:

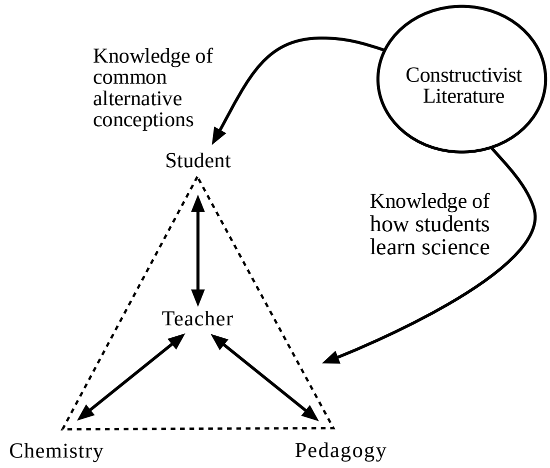

Figure 1: Constructivist research informing teaching
(Adapted from Taber (2000))

Constructivist literature thus utilizes what is explained by alternative conceptions as well as the mode of student learning and then proposes specific approaches that can best be utilized to enable student learning as well as specify roles of the instructor.

To summarize thoughts about constructivism in chemistry instruction, it is undeniable that learning can be viewed as an active process that takes place in the mind of the learner, and during which information from sources in the environment (including but not limited to teachers, textbooks and peers) is re-interpreted in terms of existing knowledge and understanding. While there may be both intra- and inter-personal activity in knowledge construction, it is generally accepted that meaningful learning requires the student to make sense of new information in terms of existing "cognitive structure." Thus a constructivist approach in instruction should have opportunities for the teacher as well as the students to re-construct for themselves the conceptual structure of the topic in the lesson. Amongst the common approaches to "pull together" the higher concepts is the methodology involving "scaffolding" which describe the teacher's or instructional materials' roles in helping the student to build edifice of a subject (Scott & Leach, 1998). What has been discussed regarding chemistry education can also be transposed to science and mathematics education.

WHAT THE NATIONAL ACADEMY OF SCIENCES SAYS

The National Academy of Sciences in the U.S.A. performs an unparalleled public service by bringing together committees of experts in all areas of scientific and technological endeavor. These experts serve *pro bono* to address critical national issues and give advice to the federal government and the public. Amongst its many endeavors is that of establishing the National Science Education Standards (NSES, 2005). The NSES were developed, in part, to change the emphasis of science education throughout the primary and secondary educational system. Table 1 illustrates the change in emphases.

Table 1
Changes in Science Instruction

Less emphasis on knowing facts	More emphasis on understanding concepts and developing abilities of inquiry
studying subject disciplines (physical, life, earth sciences) for their own sake	learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science
separating science knowledge and science process	integrating all aspects of science content
covering many science topics	studying a few fundamental science concepts
implementing inquiry as a set of processes	implementing inquiry as instructional strategies, abilities, and ideas to be learned

This is a clear endorsement for concerted efforts to seek alternatives in strategies in instruction with greater emphases on integration of knowledge instead of the hitherto discrete bits linked to specific concepts. In fact Malaysia's current science curriculum could be said to meet these intents, and it is only in the implementation stages we may see deviations from the intents with, for example, accusations about rote memory, factual learning minus applications. If we look at the Taber triangle (Figure 1) there is no doubt that there are many players and aspects to be contended with to improve science learning. Rather than 'rehashing' the debate on whether media will ever influence learning one should now look at the "what" within media (e.g., ICT?) that can be exploited to the furtherance of better instruction and learning when using instructional strategies. In fact Clark & Mayer (2002) reiterated and reinforced this contention that "... We know from hundreds of studies that it is instructional methods, not the media, that determine learning effectiveness." Simply put we should forget the polemics attached to defending a position about media and move towards the strategies that we can use with the media to enhance learning.

ICT AND LEARNING

Mayer's (2001) model on Cognitive Theory of Multimedia Learning is based on the Information-Processing Model. Presentation modality is what makes multimedia such a "powerful" medium as "it takes advantage of the full capacity of humans for processing information" (Mayer, 2001). In fact Moreno and Mayer (1999a) conducted a series of experiments and found that in a number of instances the modality effect works with students learning better when verbal input was presented "auditorily" as speech rather than visually as text!

The Information-Processing model acknowledges internal processes and the existence of short and long term memories. For mental activities, all inputs after the sensory filter are processed during short term memory and is further strengthened through rehearsal and use and maintained as long term memory. Thus knowledge is an objective representation of experience from a cognitivist perspective. With constructivists the same processing occurs, but knowledge here is a subjective interpretation of experience (through self construction and could be dependent on prior or social experience). Multimedia technology allows teachers to bring the real world to the learner through the combined use of two or more media such as sound, images, text, animation, and video. Multimedia can be used in any suitable mode to be both a presentation device as well as an enabler to learning and is therefore dependent on the strategy or methodology of use of media. This is well supported by the various approaches using information and communications technology (ICT) that can be categorized to be behaviorist or cognitivist or constructivist; and that as the ICT provide a more "open" learning opportunity, it will cater for more student-centered learning as oppose to "closed" learning opportunity that is more instructor-dependent (Ng, 2002). Thus constructivism requires a teacher to act as a facilitator helping students become active participants in their learning and make meaningful connection between prior knowledge, new knowledge and the processes involved in learning.

INSTRUCTIONAL STRATEGIES

It is claimed that traditional instruction has a well-established order, for example, according to Gallagher (1995), "Information comes first, followed by questioning to determine student understanding, and ending with some sort of problem-solving activity. While this approach is very systematic and easy for teachers to manage, it does not reflect the kind of learning which takes place in the real world." These are the instructional strategies that were said to be dominant in traditional instruction and Gallagher claimed that more effective learning can come about through problem-based learning or by other modes e.g., inquiry learning. Instructional strategies are the techniques, methods, sequences, media, and any other means we use to teach things to students. Most instructional strategies are based on educational theories (cognitive theory or constructivism for instance) are backgrounds for such strategies as inductive learning, problem-solving, cooperative learning. (Definition for instructional strategy retrieved on 15 May 2005 from http://students.ou.edu/Y/Akimi.Yesoufou-1/concepts.html). If instructional strategy is so encompassing, there is thus a need to re-look at the so-called traditional instruction which had always been subjected to ridicule. Might not traditional instruction have better strategies? The answer is yes! With a little bit of imagination on can make a better job of this approach and not be subjected to alter the modes to problem-solving, inquiry, teaching and a number of others, and it can even be constructivist! How can this be done? By varying the instructional strategy for the same contents to be learned / taught, and by providing the context for the concepts to be learnt.

DEVELOPING ALTERNATIVE INSTRUCTIONAL STRATEGIES

The premise of the study conducted and reported here is that one can improve the so-called traditional instruction by amending the strategies that are used in it. The study involved a series of three periods on "traditional instruction" on the topic 'Electrolysis'. It was a preliminary study to help "sharpen" the methodology of instruction for further investigation. The topic was considered "difficult" and also having poor attainments over the years as reported in the Annual Reports of the Examination Board (*Lembaga Peperiksaan*) of the Ministry of Education Malaysia (*Kementerian Pendidikan Malaysia*). While no reasons were attached to the weakness, it can be surmised that the relatively weak results could be adduced to weak understanding of concepts of the topic 'electrolysis', weak prior understanding of the prerequisites to electrolysis (e.g., the electrochemical series as discussed in the earlier Periodic Table and structure of an atom), poor scientific skills (including observations and deductions), wrongly comprehending the flow of electrons and ions towards the electrodes, wrongly assigning "positive and negative charges" to the electrodes, and many others. There were no indications as to how the topic could have been taught better. Perhaps it is not the Examinations Board's purview, but some agencies within the Ministry of Education could have taken the cudgels to help solve the perennial problem.

1. ***The common / traditional mode of instruction*** would appear in the following manner (Figure 2). This is quite a "normal" mode of classroom transaction in a traditional instruction environment. It involves a lot of teacher-input and teacher directed actions. Students are mostly passive, listening / looking at the visuals / taking or making notes / and answering questions posed by the teacher or the CD-ROM instruction. Looking at Figure 2 this type of instruction may be dull or even unproductive as the students are just mere observers of the lesson development all mostly conducted by the teacher. However if this type of instruction have survived through the ages there must be some redeeming worth to it. First its contents / materials are organized efficiently, so they can be covered quickly, and (mostly) economically thereby supporting the "banking theory of schooling" first introduced by Freire in 1972 (2000), whereby the teacher provides the child with a lot of "rote-learned" information. While the emphasis that permeated the traditional school was recitation, memorization, recall, testing, grades, promotion, and failure, Hirsch (1997) argues that critics of traditional instruction fail to note that for challenging subject matters - the core of traditional education - can be taught in a lively, demanding way, through what Hirsh termed as knowledge-based education, e.g., by way of critical thinking skills. It is here ICT plays a role. How do we "manipulate" the traditional instruction to one that is more knowledge-based?

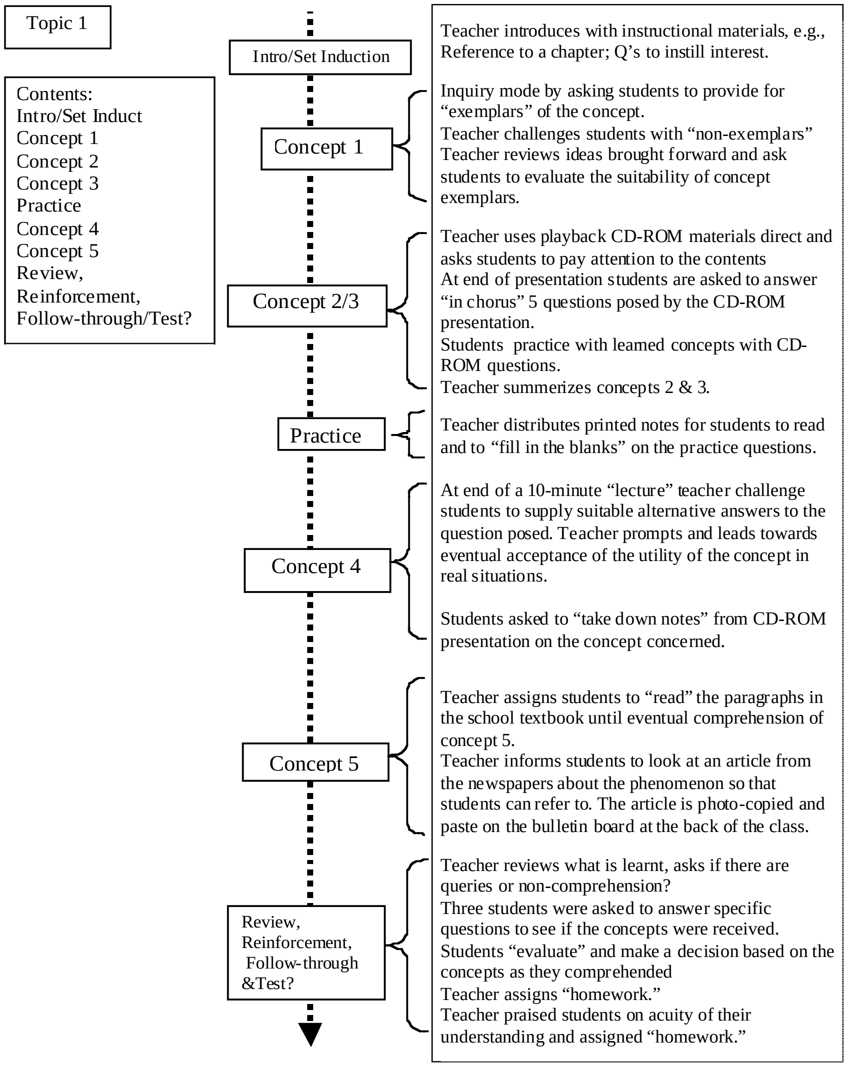

Figure 2: A typical traditional instruction sequence

2. ***Varying the common / traditional mode of instruction.*** It is quite clear that the traditional mode of instruction does have its advantages in terms of time on task and efficiency but may be lacking in better comprehension that could be improved upon with replacing certain current pedagogical strategies with constructivist strategies. Here in this research for key concepts of the lesson over a two-period instruction, alternate strategies are used as illustrated here in Table 2.

Table 2
An example of alternate strategies for the topic on Electrolysis

Current strategy	Alternate strategy
Teacher draws flow of electrons and ions towards the electrodes using coloured chalk.	Teacher illustrates flow of electrons and ions towards the electrodes using PowerPoint slide with animation.
Teacher asks questions about flow of electrons and ions towards the electrodes .	Teacher uses a second Power Point slide and ask students to "predict" flow of electrons and ions towards the electrodes
Teacher asks students to copy down the diagram on flow of electrons and ions towards the electrodes from the blackboard.	Teacher asks students to copy down the slide's diagram on flow of electrons and ions towards the electrodes
Teacher explains the different results of electrolysis using different electrodes in molten solutions from the CD-ROM visuals and attempts to correlate the phenomena observed with reference to the book's diagram about the electrochemical series; explanations are repeated and from oral questions student comprehension assessed.	Teacher illustrates using the different results of electrolysis with different electrodes in the molten solutions from the CD-ROM, and *pausing* with the CD-ROM to ask students to read out the results and asks why such results are obtained from different students till there is a semblance of the order of elements in the electrochemical series

Thus using the same traditional instructional mode, but with variance to the strategy the same topic could be taught in an alternative mode that encourages "thinking out" from the students and also not separating science knowledge from science process as suggested by NSES (2005). The study advocates an alternate pedagogical content knowledge (PCK) as a means to attain better attainments, as well as to support the contention that appropriate PCK is the way forward in using ICT in instruction (Ng, 2005). Such student participation is more aligned to constructivist viewpoints about knowledge construction. And so with this alternative method of traditional instruction prepared, a study was conducted to find out if it is better with this method when compared with the traditional mode with reference specifically to the sections/ transactions used in the traditional mode.

METHODOLOGY

A quasi-experimental research using pretest-posttest design was conducted on two classes of students with equivalent backgrounds in terms of prior knowledge and academic attainments based on the most recent Lower Secondary School Evaluation (*Penilaian Menengah Rendah*) public examinations results. The pretest was administered just immediately after the conclusion of the topic on the Periodic Tables. The posttest was conducted one week after the end of the lesson on Electrolysis and coincided with the monthly test. A unique variation is that the posttest questions (similar to the pretest items) were embedded into the monthly test items thereby also overcoming immediate "recall" of test items by the students, and also to ensure that all or most students participate in the posttest with real efforts as it was part of a monthly test and not a one-off inconsequential test. For the Electrolysis topic there were 15 multiple choice/short answer questions covering the whole topic, and in these nine were specifically tied to the changes in instructional strategies or approaches in the experimental group. The total score for the topic Electrolysis added up to 100 and of these 65 belonged to the alternate instructional strategy mode. There were 35 and 31 students for the control and experimental groups, and these groups are assigned the treatments by a simple "toss of the coin." Thus the pretest, treatment, posttest quasi-experimental design was utilized and this thus entailed the use of simple comparison of means of attainments of students as well as correlation between these scores with scores of prior states, viz., students' performance in the *Penilaian Menengah Rendah* (Lower Secondary School Evaluation) and these were converted to three equal groups of "high," "medium"' and "low." Despite the precaution taken to ensure all students take their tests, the eventual number of students for the control and experimental groups with all data completed were respectively 33 and 29. The posttest composed of two component scores, viz., full scores of 100% called "Post_100", scores amounting to 65% representing those items/materials where there were alternative strategies compared to the current strategy in instruction, and was called "Post_65", and scores amounting to 35%, being the remainder of the test items referring to "common topics/items taught using the current strategy to both groups" and called "Common." The pertinent results of the analyses are displayed below:

Table 1
Statistics of the Pretest and Posttest scores

	N	Minimum	Maximum	Mean	Std. Dev.
Pretest	62	38	73	59.19	8.23
Post_65	62	30	60	47.16	7.33
Post_100	62	60	99	77.12	7.28
Common	62	16	35	29.96	3.53

Table 2
Analysis of Variance on "Pos_65" between treatment groups

Source	Type III Sum of Squares	df	MS	F-Ratio	Sign.
Intercept	138267.60	1	138267.60	2881.00	.000*
Treatment	398.80	1	398.80	8.31	.005*
Error (within)	2879.57	60	47.99		
Total	141163.41	62			

* Treatment is significant at <0.05

Table 3
Analysis of Variance on "Pos_100" between treatment groups

Source	Type III Sum of Squares	df	MS	F-Ratio	Sign.
Intercept	368262.74	1	368262.74	7222.21	.000*
Treatment	175.31	1	175.31	3.44	.069
Error (within)	3059.41	60	50.99		
Total	371996.34	62			

Table 4
Analysis of Variance on "Common" between treatment groups

Source	Type III Sum of Squares	df	MS	F-Ratio	Sign.
Intercept	55226.43	1	55226.43	4634.22	.000*
Treatment	45.288	1	45.29	3.800	.056
Error (within)	715.02	60	11.92		
Total	56422.67	62			

The statistical analyses revealed that for all three ANOVAs with dependent variable being Post_65, Post_100 and Common (Tables 2, 3 & 4 refer) with the independent variable of Treatment, only F-Ratio for Pos_65 is significant. This implies that the means of the two groups of students are significantly different. A *t-test* was thus conducted to determine the means for the two groups of students with Pos_65 as the dependent variable. The two groups differ significantly in their group means at 48.70 and 44.68, for the alternate strategy group versus the common strategy group (see Table 5).

Table 5
t-test of "Pos_65" with treatment

	Treatment	N	Mean	Std. Dev.	t	df	Sign. (2-tail)
Post_65	Alternate strategy	29	48.70	7.68	2.206	60	.031*
	Current strategy	33	44.68	6.68			

Further it was revealed that although using an alternative instructional strategy may help students in attaining better scores for the topic, it is only effective for questions related to the contents taught with the alternate mode. When the total posttest scores were compared there were no significant differences in total posttest. A further analysis for "Common", being the balance of the 35% of the scores where the contents referred to are taught similarly with the "current strategy", showed that both groups of students do not differ in their means for "Common". Tables 6 and 7 confirm the analyses.

Table 6
t-test of "Pos_100" with treatment

	Treatment	N	Mean	Std. Dev.	t	df	Sign.(2-tail)
Post_100	Alternate strategy	29	78.99	7.37	1.854	60	.069
	Current strategy	33	75.55	6.93			

Table 7
t-test of "Common" with treatment

	Treatment	N	Mean	Std. Dev.	t	df	Sign.(2-tail)
Common	Alternate strategy	29	29.05	4.07	-1.949	60	.056
	Current strategy	33	30.76	2.80			

As the pretest and *Penilaian Menengah Rendah* scores are also available, an initial Pearson correlation analyse was conducted to see if these variable are inter-correlated. If they were then it would only be proper that these pre-existing factors be accounted for or used as covariate(s) in a subsequent analysis. The correlations appear as in Table 8.

Table 8
Pearson Correlations of Pretest, Posttests, "Common" and Treatment

		Treatment	Common	Post_100	Post_65	Pretest
Penilaian Menengah Rendah (PMR)	Pearson Correlation	.021	-.085	.668 **	.705 **	.734 **
	Sign. (2-tailed)	.970	.511	.000	.000	.000
	N	62	62	62	62	62
Pretest	Pearson Correlation	-.025	-.103	.563 **	.609 **	
	Sign. (2-tailed)	.845	.427	.000	.000	
	N	62	62	62	62	
Post_65	Pearson Correlation	-.349 **	-.255 *	.883 **		
	Sign. (2-tailed)	.005	.046	.000		
	N	62	62	62		
Post_100	Pearson Correlation	-.233	.228			
	Sign. (2-tailed)	.069	.074			
	N	62	62			
Common	Pearson Correlation	.244				
	Sign. (2-tailed)	.056				
	N	62				

As can be seen, there were a number of significant correlations between the PMR with the Pretest, Post_65 and Pos_100. The Pretest and two of the posttest scores are significantly correlated, and then Post_65 is correlated to Post_100, and "common". The last is to be expected as Post_65 contributes to Post_100 (the total posttest score), but how it (Post_65) is related to "Common" may be difficult to justify as the scores for "Common" is supposed to represent parts of the topic of Electrolysis that is taught in the current strategy for all students. The only commonality is that all these items taught in what ever strategy belong to the same topic, and this may be the reason for the correlation. The main intent of the study is focused on Post_65, that is the part of electrolysis that is taught using the traditional current approach and the alternate approach (these being the Treatment), and thus a final analysis on Post_65 as the dependent variable and using Treatment as the main factor with Pretest and *Penilaian Menengah Rendah* (PMR) as the covariates. The results of this Analysis of Covariance (ANCOVA) are shown in Table 9.

Table 9
ANCOVA of Post_65 by Treatment with Pretest and PMR as Covariates

Source	Type III Sum of Squares	df	MS	F-Ratio	Sign.
Intercept	679.64	1	679.64	33.594	.000*
Pretest	41.96	1	41.96	2.074	.155
PMR	524.14	1	524.14	25.908	.000*
Treatment	416.22	1	416.22	20.573	.000*
Error (within)	1173.39	58	20.23		
Total	141163.41	62			

* Treatment and PMR are significant at <0.05

Thus by excising the effects of the PMR and the Pretest on the Post_65, there were significant differences in this dependent variable between groups as the Treatment variable is significant at <0.05. Note that PMR is also a significant contributor to the differences between means of the two groups of student under the two treatments. However now Pretest is not contributing to the Post_65 scores, as most of those variances could have come from the PMR but is not halved off when a Pearson correlation analysis is done.

DISCUSSION

Thus the quasi-experimental design research had illustrated the possibility of improving science or mathematics instruction in the traditional direct-instruction mode using alternative strategies as spelt out in the earlier section. The effects of this alternative strategy seem only to be viable for attainments that refer to the items or part of the lesson on Electrolysis where alternate strategies were applied, and this alternative strategy instruction does not confer any advantage to other parts or items in the instruction where it was normally taught. Hence the treatment as a variable has no effect on Post_100 or "Common". This study thus confirms that using alternate strategies that elicit participation of the students, teacher probing on the reasons for the arrangement of elements in the electrochemical series, active "reading" from projected multimedia images as opposed to hand-written chalk diagrams, may have assisted in elevating students' scores in those parts of the lesson where alternative strategies are used. The learning accrued from these alternative strategies apparently does not carry over to parts of the lesson where it is taught in the "current" or traditional mode. Thus when combining Post_65 with the balance "Common" into a final Post_100 score there were no observed differences in attainments of the students by treatment modes. This was quite unexpected as Post_65 carries a major part of the total posttest, but then it may be more due to the fact that the advantage accrued to Post_65 in the alternate strategy is not so yawningly big as to offset the final total posttest scores.

As a concluding statement it appears that more variability should be incorporated into the traditional direct instruction modes and this can include use of some strategies that mirror the proposed of a creation of constructivist learning environments (Jonassen, 1999). This study thus can be said to support classroom teachers in recommending that they vary their instructional strategies and in so doing help "enliven" the classroom climate as well as to provide viable avenues to test out new ideas about instruction without being too much involved in debating on the advantages or otherwise of the various philosophical and theoretical perspectives.

REFERENCES

Clark, R. C., & Mayer, R. E. (2002). *E-learning & the science of instruction*. San Francisco, CA: Jossey-Bass Wiley.

de Jong, O. (2000). Crossing the borders: chemical education research and teaching practice. *J. Chem. Ed. 4 (1), April*, 31-34

Freire, P. (2000). The Banking Concept of Education. In Elisabeth C. Gumnior. (Ed.). *Entering the Parlor: Communications, Conversations, Writing.* (2nd Ed.) Boston, Massachusetts: Pearson, 97-109.

Gallagher, S. (1995). Implementing Problem-Based Learning in Science Classrooms. *School Science and Mathematics, 95 (3) Mar 1995*, 136-46.

Hirsch, E. D. (1997). Why traditional education is more progressive. The American Enterprise, March / April 1997, 42-45. Also available at The American Enterprise Online accessed 19 May 2005 from http://www.taemag.com/issues/articleid.16209/article_detail.asp

Johnstone, A. H. (2000). Chemical education research: Where from here? *University Chemistry Education*, *4*, 34-38

Jonassen, D. H. (1999). Designing Constructivist Learning Environments. In C. M. Reigeluth (Ed.). *Instructional-design theories and models. vol. 2. A new paradigm of instructional theory*. Mahwah, N.J.: Lawrence Erlbaum Associates.

Lasley, T., Matczynski, T. and Rowley, J. (2002). *Instructional Models: Strategies for Teaching in a Diverse Society.* Belmont, CA.:Wadsworth Group.

Mayer, R. E. (2001). *Multimedia learning.* Cambridge, UK: Cambridge University Press.

Moreno, R. & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91,* 358-368.

National Science Education Standards (2005). Retrieved on 15 May 2005 fromhttp://www.nap.edu/readingroom/books/nses/ .

Ng, W. K. (2002). *ICT dan Pengajaran.* Siri Syarahan Umum – Pelantikan Profesor. Penang: Penerbit Universiti Sains Malaysia

Ng, W. K. (2005). ICT Integration in Classroom Instruction – Making it work for You and for Your Students. Paper presented at *First National Training Programme for Teacher Educators on ICT-Pedagogy Integration Workshop* organized under the Japanese Funds-in-Trust (JFIT) Project held in SEMEO RECSAM, Penang, Malaysia, 6-10 June 2005.

Schank, P. & Kozma, R. (2002). Learning Chemistry Through the Use of a Representation-Based Knowledge Building Environment. *Journal of Computers in Mathematics and Science Teaching, 21*, 253-270.

Scott, P. and Leach, J. (1998). Learning science concepts in the secondary classroom (3rd Ed.). In M. Ratcliffe (Ed.) *ASE secondary science teachers' handbook.* London: Simon and Schuster.

Shamsudin Jalil, Mod. Shah Bachik & Zaidah Shuib (1996). Pelaksanaan kurikulum sains KBSM: Jurang antara hasrat dan amalan – Perspektif Jemaah Nazir. Paper presented at the *Seminar Kurikulum Sains Kebangsaan Ke Arah Pendidikan Sains Bertaraf Dunia,* 16-21 December 1996, Langkawi, Malaysia.

Taber, K. S. (2000). Chemistry lessons for universities? A review of constructivist ideas, *University Chemistry Education*, *4*(2), pp.26-35.