DOCUMENT RESUME

ED 337 448 SP 033 353

AUTHOR Cheung, K. C.; Toh, K. A.

TITLE In the Eyes of the Beholder: Beginning Teachers' Conception of the Nature of Science and Science Teaching.

PUB DATE Oct 90

NOTE 25p.; Paper presented at the Annual Conference of the Educational Research Association (4th, Singapore, October 20-21. 1990). Best available copy.

PUB TYPE Speeches/Conference Papers (150) -- Tests/Evaluation Instruments (160) -- Information Analyses (070)

EDRS PRICE MF01/PC01 Plus Postage.

DESCRIPTORS Elementary Education; Elementary School Science; Foreign Countries; Higher Education; Science Education; *Science Instruction; Science Teachers; *Teacher At.itudes; Teacher Education; Teaching Methods

IDENTIFIERS *Constructivism; *Reflective Teaching; Singapore

ABSTRACT

This paper seeks to explore how beginning elementary school teachers (N=161) in Singapore conceive the scope and nature of science and to understand the relationship between those views and their present approach to, as well as their past experience of, science teaching and learning. Results of an inquiry into the teachers' views indicate that these views are generally piecemeal and may not form coherent conceptual systems. These views are also at variance with those philosophical and historical views that are proposed by Popper, Kuhn, Lakatos, and Feyerabend. Some epistemological obstacles towards a constructivist pedagogy are discussed. Based on one model of teacher education and professional development, some suggestions on how teachers can consciously monitor and develop their pedagogy are provided. The findings provide a knowledge base for a more systematic intervention study in the local context in the future. (Author/IAH)

ED337448

In the Eyes of the Beholder:

Beginning Teachers' Conception of the

Nature of Science and Science Teaching

K. C. Cheung and K. A. Toh

Institute of Education
Republic of Singapore

Paper presented to:

Fourth Annual Conference of the Educational Research Association
- Towards School-Based Curriculum Research and Development,
20-21 October 1990, Singapore.

Abstract

This paper seeks to explore how beginning elementary school teachers in Singapore conceive the scope and nature of science, and to understand the relationship between these views and their present approach to, as well as their past experience of, science teaching and learning. Some epistemological obstacles towards a constructivist pedagogy are discussed. Based on one model of teacher education and professional development, some suggestions on how teachers can consciously monitor and develop their pedagogy are provided. The findings provide a knowledge base for a more systematic intervention study in the local context in the future.

INTRODUCTION

Teachers' Alternative Conceptions in Science

Teachers, as well as pupils, hold different conceptions of science. For example, four conceptual models have been identified on how both teachers and pupils view the flow of electricity along a closed circuit, and how energy is transformed or used up when a light bulb is connected by electrical wires to a battery (Osborne, 1983; Ameh, 1986). Results show that teachers are not always superior in their grasp of science concepts compared to their pupils (Ameh, 1986). Some teachers, despite their high education levels, have misconceptions of science phenomena in some major concept areas (Lawrenz, 1986). Shuell (1987), amongst others, remarked that an adequate understanding of science education must consider not only the prior knowledge and alternative conceptions of pupils, but also those that are held by science educators. Interestingly, an examination of science teachers' concept of what is meant by an animal in Nigeria and Australia showed no evidence of cultural influences on the alternative conceptions of science (Ameh and Gunstone, 1986). Consequently, it appears that both teachers and pupils are suffering from inadequate understanding in science concepts and their misconceptions show relatively little variance across cultures.

Teachers' Conception of the Scope and Nature of Science

Hodson (1988) attributed two major causes to the failure of science curriculum development in improving pupils' understanding in science. These are teachers' inadequate views of the nature of science, and misunderstanding of, the philosophical stance implicit in the science curricula. Some teachers still subscribe to a single rigid view of science -- that of an inductivist view (Rowell and Cawthron, 1982). Pupils in teacher-directed classrooms were found to have poorer understanding of the nature of science compared with their peers in self-directed learning situations (Raghubir, 1979; Shymansky and Penick, 1981). In line with the contemporary view that learning is a meaning construction process, Benson (1987) proposed that science educators consider scientific progress from a historical-hermeneutical view, instead of an empirical-analytical view, so as to focus on meanings in the interpretation of events.

Hodson's (1988) review summed up the present situation aptly. He commented that "there was too much emphasis on inductive methods, a too-ready acceptance of an instrumentalist view of scientific theory, a serious underestimate of the complex relationship between observation and theory, and a neglect of the activities of the scientific community in validating and disseminating scientific knowledge". In addition, he made a valuable point that curriculum developers have confused the teaching of science as inquiry with the teaching of science by inquiry.

Teachers' Conceptions of Teaching and Learning

Teachers, because of their belief systems and past schooling experiences, hold different conceptions of teaching. These alternative conceptions, when exercised in classroom practices, need not be exclusive of one another nor are free from conflicts amongst themselves (Hewson and Hewson, 1987). Russell and Munby (1989) ncted that the nature of science and scientific knowledge as communicated through classroom discourse can be understood by considering the language used in science teaching. For example, similiar terms from different areas of discourse can have very different meanings, since language not only describes our world, but also substantially creates it. Russell and Munby further remarked that a teacher's personal interpretation of his teaching from his classroom experiences as well as his theoretical position about how children learn will benefit from a fruitful, metaphoric, dialectic dialogue between observation of phenomena and language use. Through reflection-in-action familiar classroom events can sometimes be re-interpreted by teachers in radically different ways. This idea of reflection-in-action was first suggested by Schon (1983).

One conception of teaching, which addresses pupils' alternative conceptions explicitly, has been examined in detail by Hewson and Hewson (1987). This Conceptual Change Model of teaching is premised on the assumption that learning is a meaning construction process and a teacher's conception of teaching will influence the decisions on how to implement a science curriculum. In this model, the ideas of intelligibility, plausibility, and fruitfulness are used to explain five categories of conceptual learning outcomes. These are, namely, (1) pupils remain undisturbed despite instruction; (2) pupils hold multiple perspectives but persist to hook on to the old ones; (3) pupils have their misconceptions reinforced during instruction; (4) pupils are undecided on what views to take because each is equally plausible; and (5) pupils attempt to foster a unification of the old and the new concepts. A sixth category could perhaps be added -- that pupils naively abandon old concepts for more scientific ones. Teaching for conceptual development was attempted by Fowler and Bou Jaoude (1987) using hierarchical concept/proposition maps to plan science lessons that explicitly addressed pupils' existing and potential misunderstandings in science. A number of research on the use of constructivist approaches in natural classroom situations is also currently taking place (for example, see Brown and Clement, 1990 on the use of analogies).

THE STUDY SAMPLE

A probing questionnaire was used to gather information on beginning teachers' conceptions of the scope and nature of science, and of their present approach to, and their past experiences of, science teaching and learning. The sample in this study comprised 161 beginning elementary school teachers in the Class of 1991 Certificate in Education Programme offered by the Institute of Education, Singapore. These teachers have not received university education and are all high school (Grade 12) graduates.

THE PROBING QUESTIONNAIRE

Altogether, there are four free response type questions in the probing questionnaire. The beginning teachers were requested to answer them as fully and honestly as possible. They were also assured of the confidentiality of their responses. The four questions are:

1. What, in your view, is the scope of science? How do you demarcate between science and non-science?

2. What do you view as the nature of science? How do you think that scientific knowledge is being developed by scientists?

3. With your view of the nature of science, tell us how you can teach according to this view.

4. How is your teaching described above different from that of the science teachers who taught you when you were schooling?

RESULTS

The first part of the results is a concise summary of the responses to the questionnaire. The second part that is presented in the next section contains excerpts of some typical views. The percentages reported below do not indicate precisely the proportion of teachers holding a particular set of views because teachers may phrase their views differently. The percentages merely represent the proportion of teachers mentioning particular views in answer to the questions. The first impression is that their views are generally piece-meal and may not form coherent conceptual systems. At times these are even in conflict with one another. The second impression is that these views are at variance to those philosophical and historical views that are proposed by Popper, Kuhn, Lakatos, and Feyerabend. Clearly the beginning teachers have not reflected on these views before. With these caveats in mind, the views and the percentages should be analysed collectively and interpreted holistically to obtain both the content and extent of some typical views held by beginning teachers on science and science teaching. In addition, these views should be understood in the light of their past schooling experiences. The following is a summary of the results:

Scope of Science and Demarcation between Science and Non-Science

Amongst the 161 beginning teachers in the Certificate in Education Programme, sixty-nine percent agreed that the scope of science is very wide. It may include everything that concerns the discovery of the universe and exploration of relationships between man and environment. It provides the "how" and "why" of our enquiries. Only eight percent gave firm indications that there is no clear demarcation between science and non-science. Seventeen percent of the beginning teachers opined that science can be tested and proven by experiments, thereby differentiating science from customs, beliefs and myths. Sixteen percent viewed science as involving studies of biology, chemistry and physics. Possibly, it includes astronomy, mathematics, and geography as well. However, art, history, language and music are not likely to be included. Only one teacher pointed out that science possesses humanistic dimensions as well.

Eleven percent of beginning teachers treated science as a body of knowledge or truths as discovered or experimented by scientists. Nine percent viewed science more specifically as activities deploying the use of science process skills such as observation, hypothesis testing, and interpretation. Only three percent, four percent and five percent respectively mentioned that science can enhance or deteriorate the quality of our lives, that scientific knowledge can be explained by theories, that science requires logical reasoning for problem solving. A few teachers provided answers that do not make any sense at all.

Nature of Science and the Development of Scientific Knowledge

The most common view expressed is that scientific knowledge acquisition is a discovery process, and with no careful description of what this actually entails. Ninety-six percent of the beginning teachers endorsed this view. That scientific knowledge is produced by investigations and explorations, which are normally systematically carried out by scientists, was also mentioned by forty-three percent of the respondents. Thirty-one percent endorsed science as a way of finding out and of knowing. Fourteen percent were of the view that the main activity of science is acquiring and refining knowledge. Eleven percent gave the view that scientific knowledge is developed using problem-solving skills and three percent thought that science is developed through trial and error in experimentation. Seven percent asserted that curiosity engenders science knowledge development and four percent pointed out that scientific attitudes are important in scientific enquiries. Only three beginning teachers indicated that science involves rational thinking while only one expressed a humanistic view that scientific knowledge is a search for self-existence and values of mankind. Others may possess such a view but did not express it.

Thirty-four percent specifically mentioned the use of hypothesis testing in the experimental procedures. Not many described in detail the process of hypothesis testing. Only fourteen percent attempted to argue, mostly in an inductive way, that scientific knowledge is produced starting from observations, through hypothesis testing, to the scientific theories. A small percentage of teachers (eight percent) asserted that scientific knowledge needs to be proved to be true. Only a meagre six percent mentioned that scientific knowledge is tentative and fallible. An even smaller four percent thought science should build upon past experiences and prior knowledge. Whether this prior knowledge should be used to inform theory-building is not indicated at all. It is still noteworthy to learn that four percent of beginning teachers thought that science progresses from an evaluation of proposed theories and this should be carried out before experimentation begins. One beginning teacher was able to point out that scientific knowledge is only acceptable after intense debates and discussions.

Proposed Ways of Teaching Science

Fifty-eight percent of the beginning teachers stipulated that they would allow pupils to question, experiment and test out their ideas, rather than tell them the answers right away. Forty-four percent preferred student-oriented enquiries emphasising hands-on experiences, concrete materials, everyday experiences, and the living environment. Some fourteen percent declared that we should not limit the science lessons to the confines of the classroom. Ten percent of beginning teachers believed that the development of the science process skills would help pupils understand science better. An equal percentage thought that they can conduct more experiments and make their lessons more activity-based. Some six percent declared that they firmly believe that knowledge should not be imparted passively. However, two teachers thought otherwise -- that we can impart knowledge sincerely to students, especially the basic knowledge. What comprises basic knowledge was however not elaborated upon.

Six percent were of the opinion that we can encourage pupils to read widely, such as journals, research reports, and library books. Some five percent thought that we should instill moral judgements, scientific attitudes, and the humanistic aspects of science to the pupils. Two percent claimed that we can make the pupils realise that scientific principles can be tested rather than derived from the observations. Only one beginning teacher suggested we can induce cognitive conflicts to stimulate thinking.

Another one said that we can allow more discussions amongst pupils on the alternative conceptions of science.

Characteristics of Past Science Learning Experiences

Fifty-three percent of the beginning teachers said that bookish information was spoon-fed to pupils, making past teaching dull. Forty-four percent stipulated that past teaching was characteristically learning facts by rote. Sixty-six percent revealed that not many experiments were conducted because practical work and hands-on experiences were considered troublesome and hence were avoided. That classroom instruction was mainly teacher- or class-room-centred was felt by twenty-one percent of the respondents. Some eight percent confessed that science lessons were dull and uninteresting and an equal pecentage of respondents mentioned that there were frequent assessments and that instruction was essentially examination-based. Five percent of the teachers who had the opportunities to do experiments complained that not much discussions were held nor were explanations made during and after the experiments. Some three percent recalled that their science lessons did not involve many science process skills.

Two respondents said that their past science teachers usually expected a "yes" or "no" answer to questions posed. Three recalled that the questions normally did not arouse cognitive conflicts or encourage divergent thinking. Two beginning teachers had never gone into the science rooms when they were schooling. Of the 161 beginning teachers only a dismal two opined that they find their lessons and experiments enjoyable and interesting when they were at school.

Excerpts of Some Typical Views on the Nature and Process of Science

A spectrum of levels of understanding on the nature and process of science is noted. Below are some examples of these alternative conceptions running along a continuum of understanding from the unproblematic or non-sensical to a relatively fuller comprehension of the nature of scientific enquiries. Some teachers are observed to possess some of the following conceptions simultaneously without integrating these views into a coherent whole. The comments following the excerpts help the reader to understand the meanings of these statements that have been extracted out of context in the responses.

(1) "Science is anything that can be supported by facts and not assumptions." -- View of science as an unproblematic fact-gathering process.

(2) "Science is discovery basing on facts and need to be proved

to come up with hypothesis." -- Unclear conceptions and use of terminologies.

(3) "Science involves hypothesis, experiments, interpreting data and the confirming of principles and facts through observations." -- An inductivist view on the process of science.

(4) "The nature of science is to be discovered and experimented. Scientific knowledge is only developed and proven with much experimentation and exploration." -- An empirical and positivist view on the process of science.

(5) "Science is being developed through trial and error, i.e. through years of experiments, where eventually there is an explanation for every 'why', 'how', 'what' asked." -- An evolutionary view of scientific progress.

(6) "My view of the nature of science is involving process skills. These process skills have helped to develop a lot of scientific ideas." -- A view of science as a process as opposed to content.

(7) "Scientific study makes use of process skills based on a strict adherence to objectivity. Personal presumptions and prejudices, which may exist in other fields, are not exercised in science." -- View of science as objective knowledge obtained through the use of science process skills.

(8) "Scientists make hypothesis, carry out experiments to prove the hypothesis and thus coming up with a theory." -- View of science with theories stemming from hypothesis confirmations.

(9) "Scientific knowledge is based on previously formed theories and findings and further experimentation. Empirical evidence plays a large role in the nature of science." -- View of science knowledge development as a theory-driven empirical process.

(10) "The nature of science evolves around a body of language which comprises interrelated principles, laws, theories and concepts to account for what have been observed. Science also involves ability to predict what has not yet been observed." -- View of science as seeking for explanations and predictions to phenomena.

(11) "The nature of science involves problem solving. It is through the investigating of certain concepts that things are analysed and interpreted." -- View of science concepts as context-embedded that is defined by the problem-solving task.

(12) "Scientific knowledge is backed up only after intense debates and discussions." -- View of status of scientific knowledge as subjected to public censorship before release for public use.

Excerpts of Some Typical Views on a Pedagogy of Science Education

The analysis of beginning teachers' views reveals a continuum on a pedagogy of science learning that matches in a parallel manner their views on the nature and process of science. This continuum ranges from emphasis on imparting basic knowledge and values, deploying concept- and context-free process skills, engaging in discoveries and experimentation, providing personally-relevant hands-on experiences and child-centred activities, to facilitating pupils in their active construction of knowledge from concepts, principles and theories. Examples of these views are given below.

(1) "By imparting this knowledge sincerely to the students. Make known to them the values of what they are studying (science). Try and show them concrete evidence of basic knowledge that they should know." -- View of school science as imparting basic knowledge and values.

(2) "I would teach science by learning together with the pupils in the same way as scientists discover new things." -- View of school science as mimicking the way scientist operates.

(3) "Using experiments (mainly) to get them to observe the effects of the experiment and also to get them to discover for themselves." -- View of school science as emphasising experimentation, and discoveries.

(4) "Science is better taught with emphasis on developing process skills and acquiring knowledge through hands-on activities, namely, experimenting where pupils discover concepts and theories by themselves." -- View of school science as emphasising concepts derived from phenomenological experiences.

(5) "Allow pupils to speculate, to think, to explore, to know from errors, and to experience the joy of discovery through providing many interesting activities which involve full participation from the pupils." -- View of school science as child-centred and activity-based.

(6) "Children learn best when they have hands-on experience. Examples should be found from within their daily lives to relate the lesson to it." -- View of school science as something which is personally relevant.

(7) "Pupils should be active knowledge seekers rather than passive receivers. Science should not be taught by teachers who are constrained by the four walls of the class and the two covers of the book." -- View of school science as something which should not be presented in a formal manner.

(8) "Students are made aware that there are principles that determine all scientific facts and that they can be tested." -- View of school science as theory- and principle-laden.

(9) "We must not put too much emphasis on correct answers as already discovered by scientists. Curiosity in students and willingness to discover things is still a very much desired characteristic of students." -- View of school science as a quest for knowledge which is fallible.

IMPLICATIONS

In the light of the findings we will now examine some of the epistemological obstacles to a constructivist pedagogy.

The Obstacle of Didactism -- Psychologists emphasise the process of thinking as a meaning construction process, whereas philosophers view thinking as maintaining sceptical views that are based on some types of logic, whether formal or informal (Educational Testing Service, 1990). The merger of these two views such as the one exemplified by Brown (1979) is what is desired in contemporary constructivist views of teaching and learning. Viewed from a constructivist perspective, the question of whether didactic or inquiry approaches should be promoted is not a straightforward decision. Didactic approaches, which are widely applied at tertiary levels, should not be condemned merely on grounds of passive note-taking. On the contrary they can stimulate subliminal questioning while the audience is actively listening and critically evaluating. On the other hand the common complaint from teachers that inquiry approaches and Socratic teaching through dialogue are too time consuming, rendering it impossible to cover the required syllabus, is not warranted since these views undervalue the power of reasoning that is inculcated and the merits of cognitive transfer across similar learning contexts. The challenge that teacher educators are facing is that beginning teachers are often not conversant with the nature of science and its development, and the ways they should teach for conceptual understanding and procedural proficiency. The findings in this study reveal the prevalence and magnitude of this problem.

<u>The Obstacle of Viewing Scientific Concepts with Certainty</u> -- Brown (1979) likened a scientific concept to a knot in a web whose strands are the propositions that make up a theory. The meaning of a concept is defined by the knot's location in the web, which is determined by the strands that come into this knot and by connections via other strands to other knots. Theory change, which is associated with a scientific revolution, can then be explained as a dialectical reconciliation between observational anomalies and theoretical commitments. The consequence is that reconstruction of the strands of the theoretical web will confer revised meanings to concepts and fresh interpretation of observations. Furthermore, scientific knowledge is fallible and is obtained through rational consensus of the scientific community on the basis of evidence in the light of their current theoretical commitments and prevailing research environment. Such views on the nature of science and its development are clearly not grasped by our beginning teachers.

The Obstacle of a Performance Orientation -- Gilbert and Watts (1983) have used the idea of catastrophe theory, developed by Rene Thom in France, to model children's conceptual change in terms of the two constraining factors, namely, the cost and benefit of change. Only when both of these are favourable will conceptual change occur. In this theory, children's naive conceptions and conventional scientific conceptions are viewed as the two emerging stable cognitive schemes in the process of knowledge acquisition (Boyes, 1988). Without teacher intervention, children's misconceptions persist. Without taking into account children's alternative conceptions, rote learning of conventional science occurs while keeping the naive conceptions intact. However, if prior experiences are catered for and some appropriate cognitive conflicts are induced, there is a point at which children's conceptions will no longer be seen as viable. If this is so, the catastrophe will take place resulting in children's science shifting abruptly to the more fruitful conventional science. The use of negotiated, personally-relevant learning tasks will help to facilitate this change. Unfortunately, our beginning teachers see the process of learning as unproblematic. Perfomance is more valued thar understanding because of its visibility.

Teachers as Reflective Practitioners -- The way ahead is by no means straight forward, even if teachers from now on understand the fallacies in science teaching and learning. The reason is a simple one. Teachers, who were pupils before, were all the time constructing their own personal theories of teaching and learning. Teachers are also learners and hence a more fruitful perspective would be to start with them. Cheung's (1990) model of teacher development has made clear that it is the continuing self-renewal and self-directed autonomous decision making that contribute to a teacher's professional development. Teachers have to understand that classroom practice is a constructivist enterprise and that they themselves have a variety of roles to play once they step into the school confines. Reflecting on one's educational practice and internalisation of personal theories of actions under the guidance of a constructivist pedagogy are key processes in constructing one's conceptions of classroom practice. Any revision of action plans should be the result of reconciliating between theory and practice. How well the beginning teacher succeeds as a practitioner depends on the extent to which he is able to reconcile theory with practice.

EPILOGUE

In the eyes of the beholder there are different kinds of beauty. For some beholders, marriage is the tomb of the lovers. Without mutual understanding and reflection for revised plans, divorce is the outcome. Isn't this the same situation for our beginning teachers when they are married to the teaching profession?

[The authors wish to acknowledge with thanks the comments made by Miss H. K. Boo on the final draft of this paper.]

REFERENCES

Ameh, C. (1986). Common Sense Answers in Physics. Research in Science Education, 16, 31-39.

Ameh, C., and Gunstone R. (1986). Science Teachers' Concepts in Nigeria and Australia. Research in Science Education, 16, 73-81.

Benson, G.D. (1987). Open-endness in the Empirical Analytical Mode: One Conception of Scientific Progress. In: J.D. Novak (Ed.). Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Volume I, p59-66. Ithaca: Cornell University.

Boyes, E. (1988). Catastrophic Misconceptions in Science Education. Physics Education, 23, 105-109.

Brown, H.I. (1979). Perception, Theory and Commitment : The New Philosophy of Science. Chicago: The University of Chicago Press.

Brown, D.E. and Clement, J. (1990). Overcoming Misconceptions via Analogical Reasoning: Abstract Transfer versus Explanatory Model Construction. Instructional Science, 18(4), 237-261.

Cheung, K.C. (1990). To Grow and Glow: Towards a Model of Teacher Education and Professional Development. Paper presented to 1990 International Council on Education for Teaching, Singapore.

Educational Testing Service. (1990). Critical Thinking:-Critical Issues. Focus, No. 24.

Fowler T.W.,and Bou Jaoude S. (1987). Using Hierarchical Concept Proposition Maps to Plan Instruction that Addresses Existing and Potential Student Misunderstandings in Science. In: J.D. Novak (Ed.). Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Volume I, p182-186. Ithaca: Cornell University.

Gilbert J.K. and Watts, D. (1983). Concepts, Misconceptions, and Alternative Conceptions: Changing Perspectives in Science Education. Studies in Science Education, 10, 61-68.

Hewson, P.W. and Hewson, M.G. (1987). Science Teachers' Conceptions of Teaching : Implications for Teacher Education. International Journal of Science Education, 9(4), 425-440.

Hodson, D. (1988). Toward a Philosophically More Valid Science Curriculum. Science Education, 72(1), 19-40.

Lawrenz, F. (1986). Misconceptions of Physical Science Concepts Amongst Elementary School Teachers. School Science and Mathematics, 8, 654-660.

Osborne, R.J. (1983). Towards Modifying Children's Ideas About Electric Current. Research in Science and Technological Education, 1, 73-82.

Raghubir, K.P. (1979). The Laboratory-Investigative Approach to Science Instruction. Journal of Research in Science Teaching, 16, 13-17.

Rowell, J.A. and Cawthron, E.R. (1982). Image of Science : An Empirical Study. European Journal of Science Education, 4, 79-94.

Russell, T. and Munby, H. (1989). Science as a Discipline, Science as Seen by Students and Teachers' Professional Knowledge. In Robin Millar (Ed.). Doing Science : Images of Science in Science Education. London: Falmer Press.

Schon, D. (1983). The Reflective Practitioner. London: Temple Smith.

Shuell, T. J. (1987). Cognitive Psychology and Conceptual Change: Implications for Teaching Science. Science Education, 71(2), 239-250.

Shymansky, J.A., and Penick, J.E. (1981). Teacher Behaviour does Make a Difference in Hands-on Science Classrooms. School Science and Mathematics, 81, 412-422.

19 September 1990