Third Misconceptions Seminar Proceedings (1993)

Paper Title: The Problem of Terminology in the Study of Student Conceptions in Science: A Second Look

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Keywords: philosophy,Concept formation,,epistemology,scientific concepts,cognitive structures,misconceptions,constructivism,learning processes
General School Subject: biological sciences
Specific School Subject: biology
Students: secondary school

Macintosh File Name: Abimbola - Terminology
Release Date: 12-15-1993 C, 11-4-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

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The Problem of Terminology in the Study of Student Conceptions in Science: A Second Look

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ABSTRACT

This paper revisits the problem of terminology in the study of student conceptions in science. Progress on the resolution of the problem is reviewed first. Then, an analysis is performed on the knowledge of science subdividing it into components such as disciplinary, curricular, experiential, and personal knowledge. An attempt is then made to analyze how these four components of knowledge might interact in research settings to produce different contexts. Based on these analyses, it is suggested that the appropriateness of a particular term as a descriptor of science knowledge might be dependent on specific research contexts that science education researchers need to make more explicit. It seems misconceptions, alternative conceptions, and knowledge can coexist within each research context. How they might do this, and researchers' inferences about them, including underlying thought processes need to be documented. Remediation strategies would then vary with each type of conceptions and with each context.

INTRODUCTION

The problem of terminology in studies related to student conceptions in science persisted even after the 1983 International Seminar on Misconceptions in Science and Mathematics (Abimbola, 1988). A similar observation was made by Novak (1987) after the second seminar on the same theme. However, there does not seem to be much disagreement about the need for science education researchers to use terms that describe student conceptions in ways that are understandable among themselves and other readers (see Dykstra, Boyle, & Monarch, 1992; Fisher & Lipson, 1986; Gunstone, 1989; & Smith, 1991). A major difficulty is how to present an analysis of the major terms used in describing student conceptions in a manner that is acceptable to most researchers such that they would embrace the terms. The skills to use in doing this require more than mere knowledge of science education and move one into areas such as philosophy, logic, linguistics, etc. Also, part of the problem may be that science education researchers do not consider the issue of terminology in this area of research to be sufficiently problematic as to require their special attention, save occasional expression of disagreement about the use of terms in journals and at conferences (see Browning & Lehman, 1991; Lawson, 1993; Lawson & Weser, 1990; Smith, 1991; Smith & Siegel, 1993).

Since the publication of the original edition (Abimbola, 1988) of this paper, it has generated some reactions among science education researchers. For instance, while Gunstone (1989) generally agreed with the basic rationale for the paper, however, he thought that the analysis should have been more broadly focused and he attempted to rectify this. Koballa, Crawley, and Shrigley (1990), in reviewing the paper for **A Summary of Research in Science Education—1988**, described the method of analysis used in it as a funnel approach but they forgot to mention that the "funnel" had a filter paper! While all of these comments were helpful in inducing a rethinking on the earlier analysis, the first reaction to it by Yarroch (1988) provided another perspective for the analysis of the problem that is worth examining, hence, the need for this paper. Before the publication of the paper, however, Fisher and Lipson (1986) had published a comprehensive analysis of the problem of student errors using an approach different from the present one.

The purpose of this paper, therefore, is to revisit the problem of terminology in the study of student conceptions in science with the hope of generating further discussion on the problem. First, an analysis is performed on the knowledge of science by subdividing it into components such as disciplinary, curricular, experiential, and personal knowledge. An attempt is then made to analyze how these four components of knowledge might interact in research settings to produce different contexts. Based on these analyses, suggestions are presented that the appropriateness of a particular term as a descriptor of science knowledge might be dependent on specific research contexts (rather than researchers' philosophical orientation) that science education researchers need to make more explicit. It is argued that misconceptions, alternative conceptions, and knowledge can coexist within each research context. How they might do this, and researchers' inferences about them, including underlying thought processes might need to be documented in every research setting. Remediation strategies would then vary with each type of conceptions and with each context.

THE REPRESENTATION OF KNOWLEDGE

An analysis of disciplinary knowledge and the learner's relationship to that knowledge can be depicted in four distinct categories and other subcategories. The four distinct categories are: Disciplinary knowledge, Curricular knowledge, Experiential knowledge, and Personal knowledge. These categories of knowledge are expected to be dynamic and interactive, however, in

practice, only the individual learner constantly finds himself or herself struggling to make sense of these interactions. Students' personal knowledge is rarely allowed to interact in any meaningful way with the sanitized curricular and disciplinary knowledge, or at least teachers' perceptions of them. A model depicting the possible interactions among these categories of knowledge is depicted in Figure 1.

Disciplinary knowledge. Knowledge related to the discipline can be further divided into four subcategories based on their status within the discipline. The first subcategory is knowledge that is currently accepted and used, e.g., the Brønsted-Lowry acid-base theory in chemistry. The second subcategory is knowledge that was once accepted but not currently in favor, e.g., phlogiston theory in chemistry or Lamarck's theory of the inheritance of acquired characters. The third subcategory is knowledge that is candidate for acceptance to the discipline. Examples are recent research findings in published articles that are either waiting to be replicated and confirmed by other researchers or works which significance is yet to be realized and accepted by the

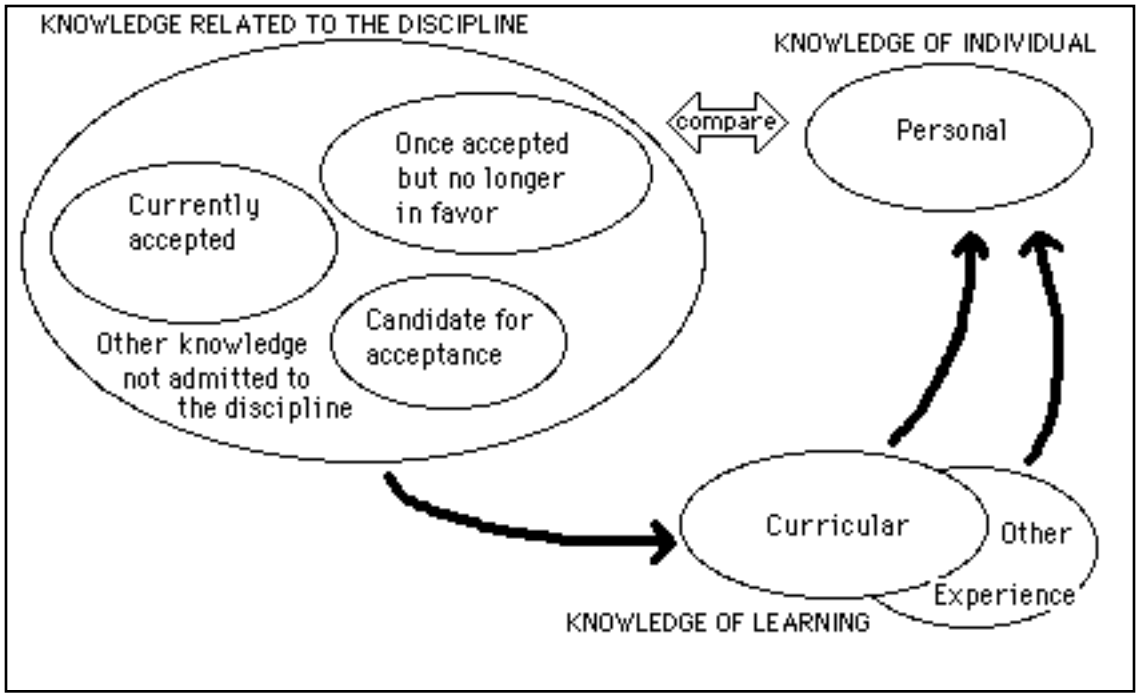

Figure 1: A model depicting interactions among disciplinary knowledge, curricular knowledge, experiential knowledge, and personal knowledge

research community, e.g., Andrew J. Wiles' proof of Fermat's Last Theorem, $x^n + y^n \neq z^n$, where $n > 2$, announced recently (McDonald, 1993). The final

subcategory is knowledge that is related to the discipline but not admitted or even a candidate for admission. Examples are: astrology, ESP phenomena and theories which are usually regarded as pseudosciences.

Curricular knowledge. Curricular knowledge is generally a subset of the disciplinary knowledge that has been selected and organized in the curriculum for instruction. According to Johnson (1977), curricular knowledge is selected on the basis of what knowledge is available and known and that can be taught and learned. Not all disciplinary knowledge may satisfy these conditions. Knowledge that would be selected from disciplinary knowledge and organized in the curriculum for instruction is usually from the type of disciplinary knowledge that is currently accepted and used. Controversial knowledge does not usually get selected into the curriculum. Knowledge that is not yet publicly known either because it is censored or obscure in various ways does not usually get selected. Also, it takes some time for recent scientific findings to enter the curriculum as knowledge. Curricular knowledge is usually found in curriculum guides, textbooks, films, tapes, and other materials. Most curricular science knowledge is found in textbooks.

Experiential knowledge. Knowledge from experience other than the curriculum is generally unorganized knowledge of the world around us as perceived by the senses. Experiential knowledge is both out there in the society and also partly in the learner's brain. Individuals come in contact with various experiences in the environment and interpretations are given to them as best individuals can until further experiences reinforce these interpretations or refute them. It does not usually require a teaching agent to acquire, although it could involve other teaching agents apart from a certified teacher. Examples are pieces of information parents teach their children, and also information picked up from the popular culture, which comes mostly through the mass media.

Both curricular knowledge and students' experiential knowledge interact in learning situations to form what can be called "knowledge of learning" that we expect students to possess in varying degrees as personal knowledge.

Personal knowledge. The knowledge possessed by an individual student—personal knowledge, is a combination of experiential knowledge and curricular knowledge as mediated by the teacher. For the average person, this knowledge—personal knowledge may be, but usually is not, similar to the knowledge of the discipline or the curriculum. There is another type of personal knowledge usually associated with children called "naive" knowledge as

distinguished from adult knowledge. This is so labelled because of children's inability to understand certain things in the same way as an adult would, e.g., conservation of volume.

A proper harmonization of the knowledge of the discipline, the knowledge of the curriculum, experiential knowledge, and personal knowledge by individuals insures that adequate learning will take place. Otherwise, learning is adversely affected if any of the different types of knowledge causes cognitive conflict in the individual.

THE STRUCTURE OF KNOWLEDGE OF THE DISCIPLINE

Disciplinary knowledge, or everyday knowledge is usually organized according to the degree of complexity, abstractness, and sophistication of the concepts involved in the language of its expression. A concept in this paper is defined as the meaning attached to a given label, word, or symbol. The degree of complexity of a concept varies from simple to complex depending on the number of concepts required for its description. Hence, a concept, say "gas," may be simpler than a "gas law" because a law requires more concepts for its statement than it is required for the meaning that is attached to the label "gas." The degree of abstractness of a concept varies from concrete to abstract. Concrete concepts are empirical or observable, i.e., concepts that can be seen, felt, or measured using any of the senses or their extensions thereof. Examples are: sodium, cell, pulley, etc. An abstract concept, on the other hand, is theoretical or unobservable, e.g., absolute zero, gene, etc. The boundary between concrete and abstract concepts may not always be clear-cut because several abstract concepts have their observable instances from which they could be inferred. The degree of sophistication, according to Carnap (1966) in Gardner (1966) varies from classificatory concepts, through comparative concepts, to quantitative concepts. Classificatory concepts are also known as descriptive concepts while comparative concepts are also known as relational concepts. Classificatory/descriptive concepts are used for grouping objects into classes according to their attributes, e.g., animals, plants, high, low, etc. Comparative/relational concepts are used for relating two or more concepts together. They are intermediate between classificatory and quantitative concepts, and they usually form the basis for quantitative concepts. Examples are: less, more, equal, inverse, proportional, etc. When applied to other specific concepts we have, higher, lower, etc. Finally, quantitative concepts are expressed in

numbers, both rational and irrational. Rather than grouping objects into heavy/light categories, or by saying one is heavier or lighter than the other without specifying their weights, if the objects are weighed and the weights are attached to them in specific units, e.g., 10/8 gms, respectively, it is then possible, using these numbers to describe and relate the objects together in a more precise manner. Figure 2 is a three-dimensional representation of the conception of the levels of organization of knowledge described above.

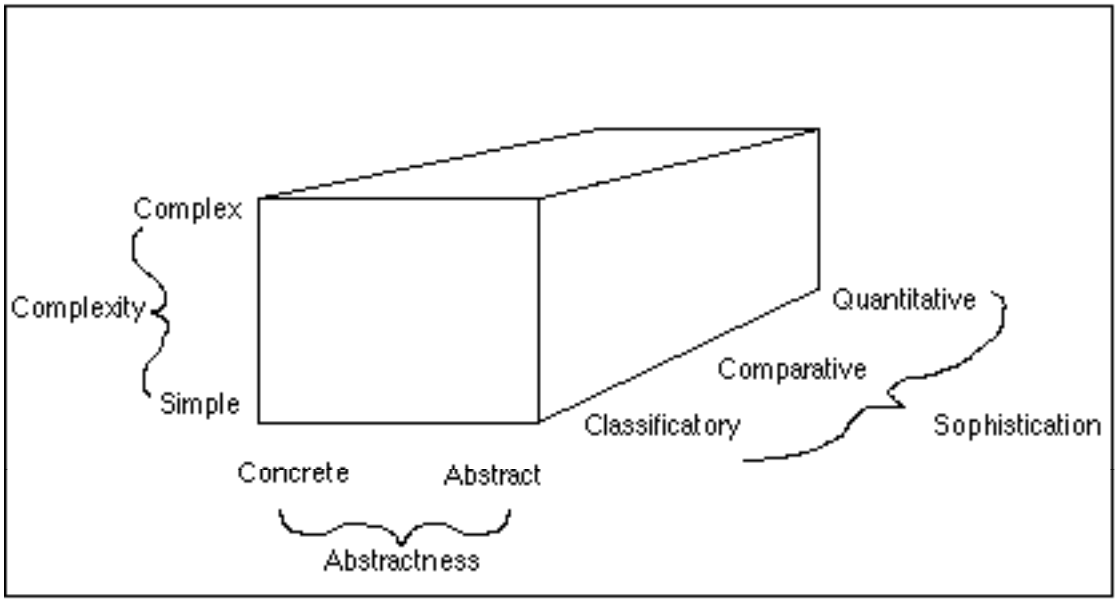

Figure 2: A three-dimensional representation of knowledge organization

Figure 3 is a two-dimensional representation of the same knowledge organization. Broadly speaking, therefore, we have two major levels of knowledge organization—high-order and low-order. At the highest level of knowledge organization we have concepts that are complex, abstract, and quantitative. At the lowest level of knowledge organization, on the other hand, we have concepts that are simple, concrete, and classificatory in nature. In between these two extreme levels, various concept combinations are possible with comparative concepts moderating their sophistication somewhere in the middle.

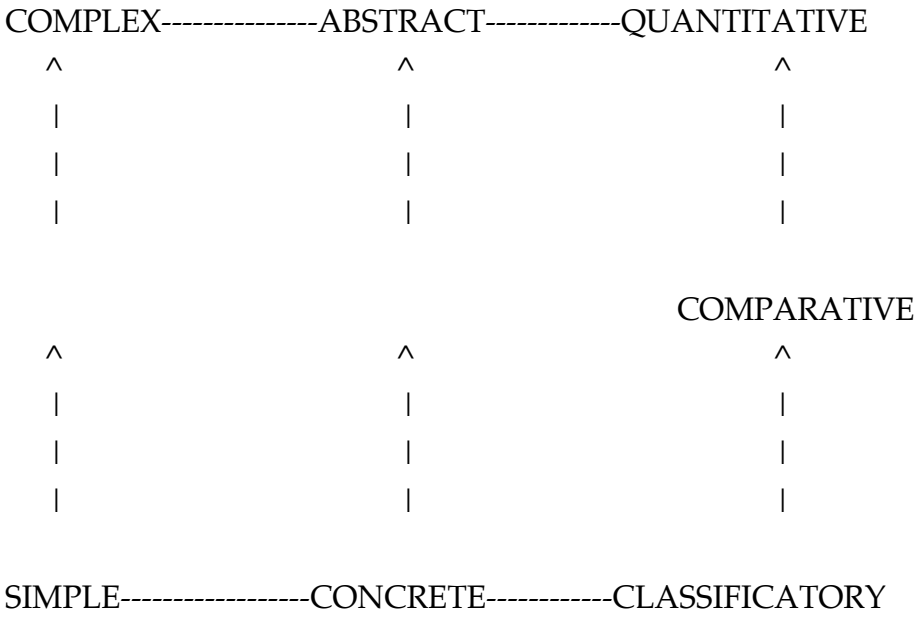

Figure 3: A two-dimensional representation of knowledge organization

In science, therefore, there are high-order and low-order levels of knowledge organization. An example of a high-order organization would be a theory, such as the Newtonian theory of mechanics. This high-order organization is essentially a "framework" upon which other consistent disciplinary knowledge can be related and understood. There are "frameworks" that are consistent with disciplinary knowledge (e.g., the Newtonian framework) and "frameworks" that are alternatives (e.g., the Aristotelian framework) to the disciplinary knowledge, and "frameworks" that are inconsistent with the disciplinary knowledge (e.g., the Creationist framework).

An example of a low-order knowledge organization would be a concept or a group of concepts that defines the relationships between a small segment of knowledge, such as the ideas related to species. Again, it is possible to have a concept (or conceptions) of species (e.g., species as ability to interbreed and produce fertile offsprings) that is consistent with the discipline, or to have a concept that is an alternative to the disciplinary idea (e.g., species as genetic similarity), or a concept (e.g., animals that look different to the eye) that is inconsistent with the disciplinary knowledge.

Similarly, curricular knowledge, experiential knowledge, and personal knowledge can exist at these two organizational levels. At the same time, the type of knowledge that will be considered acceptable within curricular

knowledge is one that is consistent with disciplinary knowledge, although this is not always the case as curricular materials such as textbooks have been found to contain information that is inconsistent with disciplinary knowledge and information that is alternative to disciplinary knowledge (Abimbola & Baba, 1993). Both experiential knowledge and personal knowledge, because they are constructed by human beings, can also exist as knowledge that is consistent with disciplinary knowledge, knowledge that is alternative to disciplinary knowledge, and finally, knowledge that is inconsistent with disciplinary knowledge which may be erroneous or just different.

FOCI OF RESEARCH ON KNOWLEDGE

In this section, analysis is performed on the foci of research on knowledge based on the type of comparisons that are possible to make among the different categories of knowledge and/or their levels of organization. If for a moment we separate concept or conceptual knowledge (of low-order organization) from framework knowledge (of high-order organization) for purposes of this analysis, the following types of comparisons are possible in research settings:

(A) Concept or Conceptual Knowledge

Compare

1. Personal conceptual knowledge <--------> Discipline conceptual knowledge
2. Personal conceptual knowledge <----------> Curricular conceptual knowledge
3. Personal conceptual knowledge <--------->Experience conceptual knowledge
4. Curricular conceptual knowledge<-------->Discipline conceptual knowledge
5. Curricular conceptual knowledge<-------->Experience conceptual knowledge

(B) Framework Knowledge

Compare

1. Personal framework knowledge <--------->Discipline framework knowledge
2. Personal framework knowledge <--------->Curricular framework knowledge
3. Personal framework knowledge <--------->Experience framework knowledge
4. Curricular framework knowledge<------->Discipline framework knowledge
5. Curricular framework knowledge<------->Experience framework knowledge

Concerning these two levels of knowledge, the following general statements are pertinent points to bear in mind:

1. Of the two types of knowledge, concept or conceptual knowledge appears to be more accessible in research settings than framework knowledge. For instance, analysis of test items (e.g., Yarroch, 1991) in comparisons involving student-related conceptual knowledge would usually reveal the nature of student conceptions and the extent of consistency with the knowledge to which it is being compared.

2. The relationship between curricular conceptual knowledge and discipline conceptual knowledge can usually be established through content

analysis. But the basis for the similarity or differences can only be a matter of speculation, if this is necessary, or should be necessary to probe at all. Also, this is purely curricular research, it does not involve students. The same comments are applicable to a comparison of curricular framework knowledge and discipline framework knowledge.

3. Research within each level of knowledge organization varies with the sophistication of knowledge in the different science disciplines. As stated by Abimbola (1988), research using physics and chemistry as content domains may be able to operate within both conceptual knowledge and framework knowledge levels. However, research using biology as content domain is likely to occur mainly at the conceptual knowledge level because of the limited number of theories in biology at present if compared to chemistry and physics.

4. Framework knowledge of students is more likely to be more deep seated than conceptual knowledge of students because of the inherent complexities of the concepts involved.

5. Methods applicable for use in investigating both types of knowledge are likely to vary with each type of knowledge. For instance, most conceptual knowledge of students may be revealed through the use of multiple-choice and essay tests. The use of the clinical interview or other similar techniques may be required to bring out students' framework knowledge.

6. Remediation strategies are likely to vary with each type of knowledge organization because of the inherent characteristics of the knowledge.

7. Apart from these intra-level comparisons, it should also be possible to compare low-order knowledge, i.e., conceptual knowledge with high-order knowledge, i.e., framework knowledge of various kinds such as: personal, experiential, curricular, and disciplinary knowledge.

REFERENCES TO DIFFERENT TYPES OF KNOWLEDGE

The position taken in this paper is that science education researchers' choice of an appropriate descriptor for the knowledge under investigation will be dependent on the context of each research. An example is the type of comparisons the researcher intends to make. It should therefore be possible to define a term that is consistent with the different types of knowledge, their levels of organization, and the type of comparisons being made that can serve as reference for research studies. The conceptual distance between the two types of

knowledge being compared should also be taken into consideration in labelling the variants of knowledge arising from the comparison in terms of the possible intervening agents between the two types of knowledge. There is also the need to specify which knowledge is being compared to which knowledge. This can easily be done if we know how each knowledge is acquired—we can only compare a piece of knowledge to its possible origin, using the origin as the standard.

(A) Conceptual knowledge. For comparisons made at the conceptual knowledge level, we propose the use of consistent conceptual knowledge to describe the knowledge that has an adequate fit with the knowledge to which it is being compared. The assumption here is that as long as human agents are involved in knowledge production, transmission and acquisition, a perfect fit may not be possible. That a piece of conceptual knowledge is consistent with the knowledge to which it is being compared does not necessarily mean that the knowledge is perfectly correct. If the conceptual knowledge is not consistent with what it is being compared, it may be possible that it is not consistent because it is just different, and it may be found consistent if other factors are taken into consideration, or, it may be clearly inconsistent and the knower may easily agree to this. We propose that the first case of conceptual knowledge that may not be consistent because it is different be referred to as "alternative conceptual knowledge" and the second one be referred to as "inconsistent conceptual knowledge." This last term is used to avoid being judgmental because available information may not permit adequate inferences from being made. Moreover, they are even not expected to be deep-seated inconsistency which students may not be able to resolve by themselves. However, if we must be judgmental, they would fall under what Kuhn (1970), Gowin (1983), and Strike (1983) labelled "mistakes."

1. When comparing personal conceptual knowledge with discipline conceptual knowledge, the discipline conceptual knowledge is to be taken as the standard. The personal conceptual knowledge may then be described as consistent conceptual knowledge, alternative conceptual knowledge, and inconsistent conceptual knowledge. It may not be easy to explain the origin of these types of conceptual knowledge because of the distance between personal conceptual knowledge and discipline conceptual knowledge. The consistency or lack of it might be due to any of the possible sources such as curricular conceptual knowledge, experience conceptual knowledge and the teacher's

knowledge. In an actual research setting, may be it is not necessary to compare students' conceptual knowledge with seemingly remote discipline conceptual knowledge unless the researcher can ensure that intervening types of knowledge such as teachers' knowledge, and curricular knowledge are consistent with discipline conceptual knowledge leaving only experience conceptual knowledge and personal conceptual knowledge to vary and modify themselves. Curricular and human constraints will severely limit the feasibility of this type of comparison. For instance, if it is assumed that the personal conceptual knowledge is being compared to discipline conceptual knowledge that is currently accepted and used, it is still possible that students' personal conceptual knowledge could resemble other types of discipline conceptual knowledge.

2. In comparing personal conceptual knowledge with curricular conceptual knowledge, the goal is usually to find out how much of curricular materials the students have learned. This type of comparison is also common in pure curricular research where inferences are made about the success or otherwise of curriculum implementation efforts from students' learning outcomes. This is Tyler's (1949) main method of curriculum evaluation. If the comparison is to be meaningful, there is the need to use students' learning outcomes in conjunction with other measures of success of curriculum implementation. This type of comparison is also common in current "misconceptions research" where the teacher factor is usually controlled by ensuring that the teacher presents the actual intended learning outcomes. This is usually achieved by the investigators actually teaching the students themselves or by training the teachers or research assistants before the teaching is done. On top of this, the researchers are expected to record the teaching sessions to ensure consistency between instructional content and curricular content. Despite these precautions, some of the students' personal conceptual knowledge could still be inconsistent with curricular conceptual knowledge because of students' individual differences concerning their experience conceptual knowledge and other factors in processing information from instruction. The personal conceptual knowledge may then be clearly inconsistent, or just alternative to the curricular conceptual knowledge. All other things being equal, the students' personal conceptual knowledge should be largely consistent with curricular conceptual knowledge.

3. A comparison of personal conceptual knowledge and experience conceptual knowledge occurs through one source, the individual because both types of conceptual knowledge, in a way, could reside in the individual. At the same time, experience conceptual knowledge is ever present in the environment and the individual may not even experience this knowledge. This is because of the fact that it is not all experience conceptual knowledge in the environment that everybody is aware of, and even when the individual is aware of it, it is not all knowledge that an individual can attend to. As has been said earlier on, experience conceptual knowledge is unorganized whereas personal conceptual knowledge is organized. The unorganized nature of experience conceptual knowledge arises from the vast amount of information that impacts on the senses every time and the challenge of dealing with this vast amount of information. Individuals cope with the volume of information through prioritization of which of them to deal with. As deliberate efforts are made to make certain information meaningful, this process may lead to some of the information being found to fit into the existing personal conceptual knowledge in some way whereas, in some cases, the conceptual knowledge may need to be reorganized to fit the experience conceptual knowledge. Some of the information in the experience conceptual knowledge may not fit the personal conceptual knowledge immediately and vice versa until, probably, much later. When experience conceptual knowledge is unable to fit personal conceptual knowledge, it may continue to retain its original structure and it does not get organized like personal conceptual knowledge. The individual deals with this situation through a process of compartmentalization of the knowledge whereby experience conceptual knowledge is used in situations where it applies only, and using personal conceptual knowledge where experience conceptual knowledge does not apply.

As long as students' experience conceptual knowledge remains unorganized and occupies memory space, it may show up occasionally with personal conceptual knowledge and this appearance influences the quality of the personal conceptual knowledge negatively, positively, or without any identifiable effect. In dealing with students, experience conceptual knowledge could show up with personal conceptual knowledge in their responses to teachers' questions or instructions, or in examinations. Since the individual controls, to some extent, both the experience conceptual knowledge and personal conceptual knowledge, their cognitive status may or may not be

known to the individual. A piece of experience conceptual knowledge which cognitive status is incorrectly judged by the individual usually appears inconsistent when tested against new experience conceptual knowledge. Whether or not the individual will do something about this situation to make it fit depends on several factors including the priority the individual attaches to the need to make the knowledge fit. So, the fact that the experience conceptual knowledge does not fit the new experience does not mean that the individual will throw away the knowledge immediately. The fact that an individual knows the cognitive status of a particular piece of experience conceptual knowledge in relation to the personal conceptual knowledge does not guarantee that the individual will use the knowledge appropriately in a new situation. So, the fact that a piece of experience conceptual knowledge is consistent with personal conceptual knowledge does not mean that it will be consistent with other types of knowledge. The relationships between experience conceptual knowledge and personal conceptual knowledge can therefore be consistent, inconsistent, and alternative, among themselves.

Since the two types of knowledge are usually constantly under test against new experiences, which could be others' interpretation of the same experience, a situation in which the two types of knowledge are judged by a student as consistent or inconsistent does not ensure consistency with new experiences. It does seem that it is only a situation in which the two types of knowledge are used as alternatives that can ensure that they are used in a manner that may be consistent with a new experience. The assumption here is that the individual would have determined which type of knowledge is consistent with each type of situation. The existence of an experience conceptual knowledge that is alternative to a personal conceptual knowledge may not be easy to detect by a casual investigator.

4. A comparison involving curricular conceptual knowledge and discipline conceptual knowledge occurs usually when evaluating curriculum materials against the discipline conceptual knowledge. This may occur at two levels, namely, a comparison between the contents of a curriculum guide in terms of its representativeness of the discipline conceptual knowledge. This comparison can be made at any of diagnostic, formative, or summative evaluation of a curriculum. A second level is a comparison between the contents of various curriculum materials such as textbooks, films, tapes, etc. with discipline conceptual knowledge to establish their accuracy. This accuracy is

usually established by having specialists in the discipline, as representatives of the discipline attest to it that particular curriculum materials are accurate representations of the discipline. Because the curriculum materials are prepared by human beings, and considering the time lag and the processes involved between the completion of the manuscript and the time the materials are published, some curricular conceptual knowledge could be found to be clearly inconsistent with the discipline conceptual knowledge. These are going to be of two types. The first type is one that is wrong due to human error. An example is a biology book stating that roots conduct water up the plant without reference to dissolved mineral salts (Abimbola & Baba, 1993). The other type is one that is just different and does not belong in science, e.g., psychic phenomena and ideas. In situations where curricular conceptual knowledge may not be clearly consistent or inconsistent with discipline conceptual knowledge relating to recent scientific findings or discipline conceptual knowledge that is going out of fashion but not yet completely gone, these are to be regarded as alternatives, especially where it is difficult for curricular conceptual knowledge to keep pace with discipline conceptual knowledge. Examples are the use of "semi-permeable membrane" and "cold-blooded animals" in high school biology textbooks whereas biologists now refer to these terms as "selectively/differentially permeable membrane" and "poikilothermic animals;" respectively, or, according to Wivagg (1988), "ectothermic animals." It is also possible for curricular conceptual knowledge to be perfectly consistent with discipline conceptual knowledge.

5. A comparison between curricular conceptual knowledge and experience conceptual knowledge should be attractive to science education researchers, too. This type of comparison may be interesting in itself, or, as an extension of a comparison involving personal conceptual knowledge and curricular conceptual knowledge. This is partly due to the unorganized nature of the experience conceptual knowledge versus the organized nature of curricular conceptual knowledge. While it may be useful to know the nature of students' experience conceptual knowledge in order to facilitate the implementation of curricular conceptual knowledge, this may not be easy to know except through students' personal conceptual knowledge. However, experience conceptual knowledge in and of itself provides legitimacy to curricular conceptual knowledge when it is incorporated into the curriculum by curriculum specialists or used in instruction by teachers. An example is the science-technology-society

curriculum which seeks to emphasize the interaction of the three to make the teaching of science relevant to students' everyday experiences.

(B) Framework knowledge. Generally, framework knowledge undergirds conceptual knowledge. A particular conceptual knowledge is therefore meaningful within a particular framework knowledge. As has been stated earlier, framework knowledge may not be accessible at the empirical level. It is usually inferred from conceptual knowledge. So, framework knowledge is consistent or inconsistent with other reference framework knowledge at the inferential level. Where two types of framework knowledge are consistent, we refer to the one being compared to a standard as consistent framework knowledge. When they are clearly inconsistent, the one that is not consistent with the standard could be referred to as a misconception. In a situation where both types of framework knowledge are not clearly inconsistent because they are just different, they could be referred to as alternative frameworks.

1. In comparing personal framework knowledge with discipline framework knowledge, personal framework knowledge could be found to be consistent with discipline framework knowledge. This could be because relevant personal conceptual knowledge is consistent with associated discipline conceptual knowledge, and is therefore traceable to the related framework knowledge. If personal framework knowledge is inconsistent with discipline framework knowledge, it is either erroneous, if it is clearly inconsistent and therefore a misconception, or it is just different, and therefore, an alternative framework to discipline framework knowledge. If personal framework knowledge is erroneous, it is not likely to be consistent with curricular framework knowledge. Also, if personal framework knowledge is alternative to discipline framework knowledge, it is likely to be consistent or alternative to curricular framework knowledge because it means that it is different from what was taught but not necessarily erroneous.

2. A comparison between personal framework knowledge and curricular framework knowledge is likely to show that personal framework knowledge could be consistent or inconsistent with the curricular framework knowledge. If the personal framework knowledge were inconsistent, then it could be erroneous, if it is clearly inconsistent with what was taught on the one hand and the discipline on the other. This is another case of a misconception. If this is not the case, then personal framework knowledge could be different from

what was taught but relatively consistent with knowledge in the discipline. This could happen in a situation where science students are ahead of the class in their readings. This is then likely going to be an alternative framework knowledge to curricular framework knowledge.

3. Personal framework knowledge is usually in constant struggle with experience framework knowledge within an individual. Each of them could be a standard to which references are made in the process of comparison. Being framework knowledge, each of them is expected to have some structure to it. When both of them are consistent with each other, this consistency could facilitate learning or not. It facilitates learning if the individual's judgment is appropriate to the situation. However, occasionally, interference sets in whereby an individual's judgment becomes unreliable against new experiences either in school or out of school. When both of them are clearly inconsistent, this might lead to misconceptions in the individual which could make learning difficult. This is because the individual could find it difficult to know which framework to use in particular circumstances. Since it is the individual that judges the adequacy and relevance of each type of framework to different situations, the chance is high that the individual's judgments could be in error, thereby misapplying each framework knowledge. This misapplication of framework knowledge could lead to misconceptions. When the frameworks are treated as alternatives, an individual's judgment is capable of being in error, too. However, because this situation could only arise when both frameworks are compartmentalized, the conceptual knowledge arising from their compartments are likely to be appropriately applied to given situations. Compartmentalization of framework knowledge could arise when an individual is unable to reconcile or reject one of two or more seemingly useful types of knowledge. Hence, some science students find it relatively easy to use ideas of evolution in the school situation while still retaining their creationist ideas for use at other settings. A case of compartmentalization of framework knowledge may be difficult to identify except through the use of techniques such as the clinical interview that can probe the individual's deeper understandings.

4. A comparison of curricular framework knowledge and discipline framework knowledge is undertaken with reference to discipline framework knowledge as the standard against which curricular framework knowledge is compared. As much as possible, curricular framework knowledge is expected to be representative of discipline framework knowledge but the two cannot be

expected to be exactly the same all the time because of reasons earlier given. As such, curricular framework knowledge is expected to be consistent with discipline framework knowledge. Where the two might differ is in terms of their sophistication. Curricular framework knowledge could represent discipline framework knowledge in a simplified, less formal manner. For instance, a biology curriculum does not need to present Darwin's theory of evolution in exactly the same manner it appeared in his original statement of the theory. In this case, the curricular framework knowledge would still be consistent with the discipline framework knowledge. On the other hand, alternative framework knowledge could be presented in curriculum materials for the purposes of learning. An example is Lamarckian evolution which is still presented alongside Darwinian evolution despite the fact that an aspect of it relating to inheritance of acquired characters has been discarded. The processes used by Lamarck to come up with his ideas of evolution are consistent with scientific framework knowledge, and these are used, at times, to teach students about scientific processes and the self-correcting nature of science. However, the creationist framework is usually judged to be inconsistent with evolutionist framework because the framework is not regarded as scientific, hence the difficulty of including it in the curriculum. Therefore, curricular framework knowledge is expected to be either consistent or alternative to discipline framework knowledge but not inconsistent with it.

However, inconsistent framework knowledge sometimes still finds its way into discipline framework knowledge, curricular framework knowledge, and personal framework knowledge because it could reside in the experience framework knowledge of individuals. For instance, Darwin (1958), in his **On the Origin of Species**, mentioned the idea of a creator breathing life into organisms. This is a case whereby an individual unconsciously allows another framework knowledge, experience framework knowledge in this case, to interfere with a scientific framework knowledge that may come to be accepted by other members of the discipline. Other instances of this situation abound in the history of science. A situation where another framework knowledge was allowed to interfere with curricular framework knowledge was reported by Roelfs (1988) where 31% of teachers in his study treated evolution along with alternative explanations that were not necessarily specified in the curriculum. Also, Abimbola (1977), Oyinloye (1991) and Seton (1985) have described situations in which superstitious beliefs held by secondary school students adversely affected

their achievements in science subjects. For instance, Oyinloye (1991) traced some of the superstitions held by students in his study to their world views concerning supreme God, life after death, dreams, destiny, etc.

5. When a researcher is interested in comparing curricular framework knowledge and experience framework knowledge, an effort should be made to clearly describe what type of experience framework knowledge is being compared to curricular framework knowledge. It does appear that it is possible to have experience framework knowledge that is not consistent with curricular framework knowledge while at the same time being consistent with discipline framework knowledge. An example is Aristotelian physics framework knowledge held by some physics students which could be inconsistent with the curricular framework knowledge, i.e., Newtonian physics, because it is Newtonian physics that is taught in schools. However, despite this inconsistency, it is not necessarily wrong as far as the discipline is concerned. It is usually considered as an alternative framework to the discipline framework. However, it does appear that a major consideration by science education researchers in determining whether or not experience framework knowledge is consistent with curricular or discipline framework is the source of that knowledge. For instance, if experience framework knowledge of science students is not consistent with science but has a parallel in the history of science, it is usually regarded as an alternative framework. However, when students' experience framework knowledge has no parallel in the history of science or is related to a framework that is not yet accepted as scientific, it is usually regarded as erroneous. What happens in a situation where students' world views are intuitive or naive and are not related to any framework that is not accepted as scientific? An example in this case is a student's superstitious belief arising from world view framework that is intuitive. Should this be regarded as alternative to curricular framework knowledge or erroneous and therefore a misconception? A problem area is what criteria to use in determining when an experience framework should be regarded as consistent or inconsistent with curricular framework knowledge. Is it consistency with discipline framework or the fact that it should not have arisen from formal instruction? Experience framework may therefore be difficult to categorize as arising from a clear-cut source that is not tainted by other sources.

SUMMARY AND CONCLUSION

An attempt has been made in this paper to revisit the issue of terminology in the study of student conceptions in science with a view to encourage further discussion on it. Another approach different from the original analysis (Abimbola, 1988) was taken in this paper to categorize knowledge into disciplinary, curricular, experiential, and personal knowledge. The structure of knowledge as symbolized by disciplinary knowledge was broadly subdivided into high order and low order according to their levels of organization. With these analyses as a basis, attention was then focused on the various comparisons among these types of knowledge that researchers might find interesting. In making these comparisons, a list of factors to be borne in mind was presented. Suggestions were then made as to what terms would be appropriate to use in describing the different types of knowledge and relationships encountered in different research settings.

The terms that have been suggested for use so far are: consistent, inconsistent, and alternative conceptual or framework knowledge depending on what types of comparisons are being made. When the comparison is between two low-order types of knowledge, we have: consistent conceptual knowledge, alternative conceptual knowledge, and inconsistent conceptual knowledge, or mistake. However, when the comparison is between high-order types of knowledge, we have consistent framework knowledge, alternative framework knowledge, and misconceptions. One could also envisage a situation whereby none of these descriptors would apply if students have nothing in their experience or personal conceptual or framework knowledge to compare with a given standard. In this case, it may be appropriate to say that the appropriate knowledge is missing. However, it appears only conceptual knowledge can be said to be missing even after interviewing the subject. It may be difficult to say that a piece of framework knowledge is missing even after rigorous probing. It may well be that the method of probing for the knowledge is not appropriate or it may be due to other reasons which would vary according to each research setting.

The analyses performed on various types of knowledge in this paper have several implications for research in the area of subject matter knowledge and conceptual change. First, the type of relationship found to exist between two types of knowledge under comparison and the levels of these comparisons would influence the remediation strategies suggested by the researcher. This could vary from the need to do nothing if the knowledge is found to be

consistent, through various strategies for reconciling alternative forms of knowledge, to suggestions as to how students' inconsistent conceptual knowledge, or misconceptions in the case of framework knowledge could be replaced.

Second, in reporting research, therefore, it would be important for science education researchers to make explicit (a) the types of knowledge they are comparing, (b) the levels at which the comparison is being carried out whether within conceptual, or framework level or across the two levels, (c) the type of relationship they think exists between the knowledge they are comparing in order for other researchers to be able to evaluate the appropriateness of their terminology, and (d) the processes undergone by researchers in making their inferences.

Third, the preceding suggestion may lead to a new area of research in science education. For instance, it may be interesting to find out the thinking processes that science education researchers went through in coming up with their findings. Science education researchers have already started interviewing scientists about their research practices (see Abrams & Wandersee, 1993), it should be possible to extend this to science education researchers interested in subject matter knowledge and conceptual change.

While recognizing that our model of the interactions among various types of knowledge and the terms suggested for use in describing the relationships may not be perfect, it is our hope that the paper will stimulate useful discussions that can be used to refine both the model and the terms.

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