AN INVESTIGATION OF CHILDREN'S IDEAS ABOUT CONSERVATION OF ENERGY WITHIN A CONCEPT-BASED MODEL

CATEGORY: Policy/Organization

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GOALS

Logical, mathematical, scientific thinking is in the mind. The goal is to train children, advantaged and disadvantaged, to think critically. The goal is for all children to understand the basic concepts of the physical and life sciences, as evidenced by their ability to carry out flexible, inquiry-based problem solving. This goal does not admit a deprived environment. Applications of the basic concepts are ubiquitous in any and all environments, rich or poor.

This dissertation begins by synthesizing this learning goal from the multitude of reports on the desired outcomes of science education. The model of science education then developed in this dissertation does not predicate student success on grade-level basic skills. The three R's are as important as ever, but they are not pre-requisite to effective problem solving. Children of the poor too often have wounded basic skills, yet they can learn to think logically and scientifically. (ASCD GOALS 1.1, 1.2)

Among science educators, it is a radical idea to un-hitch science from the basic skills. It must be supported by a solid foundation of theory and research. This dissertation devotes over 300 pages to a synthesis of the research of six eminent educational psychologists and six major approaches to science education to produce an Amalgamated Model of science education. This Model is built around three sets of distinctions.

The first set is the distinctions among curriculum, instruction, and evaluation. The second set enters uncharted waters. It distinguishes between concept, content, and process, producing a three dimensional model of science curriculum. An analysis of present science curricula show them to be two dimensional, with concept and content mixed together in one dimension and process skills being the other. The analysis also shows why a 2-D model is inherently flawed and will never accomplish the desired learning goal. In carefully defining and delineating concepts as distinct from content, the Model goes even further into unfamiliar territory by proposing a third set of distinctions that applies to concepts. Drawing from learning theory, the Model proposes that concepts can be organized for optimum learning according to three parameters: generality, complexity, and abstractness. These parameters provide an objective means of characterizing intellectual maturation. They can also be quantified. The resulting numerical ratings of the concepts are used to produce a conceptual structure that mirrors what we know about how children learn intellectually. The dissertation details such a structure for all the physical sciences.

Even though the Model is derived from theory and research, it is intended for teachers. The Model leads to two innovations needed for effective implementation. The first innovation is the delineation and organization of a sparse structure of general concepts. These concepts are, by definition, the currency of problem solving. The learning goal for a year's class is a few concepts, learned thoroughly. Content is moved from the curriculum category to instruction. The choice of specific content through which to learn the concepts becomes an instructional issue, decided at the classroom level, a radical change from present practices. (ASCD GOALS 4.1, 4.3)

The second innovation is a networked computer database of lessons and materials that are catalogued according to concept and four other major educational criteria (content, context, student performance level, and classroom management). This dissertation presents the results of hundreds of teachers' input on just what the most useful menu options would be. Besides the concept options, there are over 300 end-categories from which to choose, producing an essentially infinite number of possible combinations. Specifying the type of lesson wanted, a teacher can focus on a concept while accommodating to the local environment and student needs, interests and skill levels. Teachers can effectively address gender and minority issues, as well as interdisciplinary planning and heterogeneous grouping. It is a low-cost tool for all teachers, but in particular for those of disadvantaged students, who especially need to accommodate curriculum, instruction, and evaluation to their students. (ASCD GOALS 1.2, 3)

The lessons in the database are uploaded from other teachers. They may also originate with professional organizations, businesses, universities, and community members, who can feel assured that a submission will be accessed by teachers searching for that type of material. The networked database becomes a compelling reason as well as medium for professional creativity, sharing and outreach.

It is a practical framework within which teachers can accommodate curriculum, instruction and evaluation easily and regularly, on a daily basis. Most important, it is a Trojan horse. In the conceptual structure, it brings solid research and theory on the intellectual development of children into the classroom in a form that is appealing to teachers. (ASCD GOALS 6.4, 6.8)

PROBLEM:

The Amalgamated Model of science education is indeed a paradigm shift. It points a way to achieving flexible, inquiry-based problem solving with all students. Yet it is theory. How to test it? The approach used in the dissertation is to look for the greatest discrepancy between its predictions and conventional curricula. This disparity is in the placement and development of the concepts associated with energy. The conventional wisdom is that they are inherently difficult to understand and probably not comprehensible to students until their later secondary years. The Amalgamated Model predicts that they are available to young children who have learned to conserve the various Piagetian quantities (quantity, substance, weight, and volume). It also predicts that the specific concept that should be the starting point is conservation of energy, not work, as is the conventional pattern.

These most disparate predictions of the Amalgamated Model are investigated by searching for a link between children's understanding of Piagetian conservation and their understanding of conservation of energy. However, in true Piagetian style, understandings must be searched for independent of the subjects' vocabulary. The dissertation spends considerable effort analyzing the concept of conservation of energy, ultimately defining it as proportional causality: the understanding that a change in one abstract property is proportional to the change in another during an interaction. Thus the research hypothesis is that the ability of children aged five to twelve to conserve quantity, substance, weight and volume will correlate significantly with their ability to understand proportional causality.

RATIONALE

Correlations between the two understandings can be investigated because they can each be placed on a numerical continuum describing more specific, complex and abstract understanding. Each value can be uniquely described in terms of observable behaviors and responses of subjects, again derived from the three parameters of generality, complexity, and abstractness.

If the understanding of Piagetian conservation were in fact identical to the understanding of conservation of energy, then the correlation between the two would be very high, with a coefficient approaching one. If the two understandings were far apart conceptually, so that a variation in understanding one did not produce a variation in understanding the other, then the correlation coefficients would be very low, approaching zero. By quantitatively characterizing intellectual development and concepts according to generality, complexity and abstractness, it is possible to judge the degree to which two concepts are linked. This linkage describes the degree to which one concept develops from another.

SIGNIFICANCE OF THE STUDY

The experimental approach used in this dissertation could be used to map the actual conceptual development of children, providing a new avenue of investigation for researchers presently focusing at the micro-scale of individual mis/prior/alternate conceptions. It also provides a theoretical context, presently unavailable, within which to understand the multitude of studies of these individual conceptions. The three parameters of generality, complexity, and abstractness were derived from studies that spanned many different ages, cultures and times, and thus should be applicable to the vast majority of students' intellectual development.

The Model's foundation deep in cognitive psychology is balanced by an equally deep foundation in the classroom. Concepts cannot be learned unless students have extensive practice applying them (the "flexible" part of problem solving). These applications must accommodate to student backgrounds, needs and interests. The extensive development in this dissertation of a database to store and retrieve classroom materials according to educational criteria is an inherent part of the Amalgamated Model. It is also what matters to classroom teachers. (The computer program for the database has actually be written and tested, with extensive specifications presented in the dissertation.)

RESEARCH DESIGN AND PROCEDURES

At its greatest diversion from the conventional, the

Amalgamated Model predicts that the concept of conservation of energy should grow from the understanding of Piagetian conservation. It should be this point of greatest tension at which the Amalgamated Model would be most vulnerable. As such, it is the most likely focus of investigation to prove the model wrong. Conservation of energy is hypothesized to be a later mutation of a thinking pattern that stretches back to infancy. The Piagetian understanding of conservation is placed on a continuum ranging from zero to eight, reflecting an increasingly deeper, more complete understanding according to the three parameters of generality, complexity, and abstractness. Similarly, understanding of conservation of energy is translated into a continuum of increasing values. The statistical correlation of these two continua measures their degree of overlap, or parent-child relationship. The data is rank data, and therefore the correlation coefficients are derived from a Spearman correlation. A multiple regression correlation is also used to measure overlap at a larger scale than the Spearman correlations.

The Piagetian tasks were very easily placed on a continuum, since the classical sequence established by Piaget is also in an order of increasing specificity, complexity, and abstractness, not surprisingly. The energy data were derived from three clinical interviews-about-instances, each producing a continuum of its own with five values. One instance was of candles heating pans of water. The other two involved balls rolling down a ramp, sometimes into a closed box. The instances were designed to cover very different energy forms, thus testing the generality of the energy understanding. The three energy tasks were themselves correlated to map the connections between them, independent of the Piagetian understanding.

These interviews were first developed as prototypes tested on 39 subjects. The interviews were modified accordingly before being administered for the formal investigation. For this second stage, 48 subjects, aged five to twelve years old, were randomly drawn from the class lists of a predominately white, middle class school district. None of them had been taught topics in school related to energy. Nevertheless, the subjects were interviewed at home to minimize their attempts to parrot answers that might have been picked up at school. The interviews were audio taped so that their responses could be analyzed later. In the prototype development, the interviews and analyses were carried out by four people to measure how much variation in the data would result merely from different investigators being used. Since negligible variation was found, the formal investigation and data analysis was carried out entirely by the author.

FINDINGS

A scattergram of the data showed two large-scale patterns: About half of the subjects who understood Piagetian conservation also understood conservation of energy; most subjects (about 90%) who understood conservation of energy understood Piagetian conservation. The Spearman correlations provided more specific and highly significant data. They clearly indicated the ordering of the three energy interviews into a continuum of increasing understanding that could be explained theoretically. They also provided a statistical corroboration of the two large-scale patterns evident in the scattergram. The multiple regression analysis using the Piagetian understanding as the dependent variable produced an adjusted R-square of .25 (with a significance of .0014), indicating that 25% of the variation in the subjects' understanding of energy could be linked to the variation in their understanding of Piagetian conservation. The corresponding multiple correlation R (= 0.55) was indeed intermediate between 0 and 1, as was expected for a measurement of the degree of overlap between a concept and its immediate progenitor.

Further interpretation of these correlation coefficients is difficult. What can be said is that meaningful data does reside somewhere within the bounds of a zero correlation and a correlation of 1.0. It is valuable as a new, statistically robust parameter that needs a context of other data to become meaningful. As the first investigation of this kind, there is no comparable data concerning other relationships within the larger fabric of the conceptual map. This investigation produced numerous possible questions for future investigations of conceptual structures upon which to base curriculum design.

CONCLUSIONS AND RECOMMENDATIONS

The results of the investigation indicate that students could understand energy concepts at a much younger age than presently believed. Since these concepts are pivotally important to the ability to carry out flexible, inquiry-based problem solving, the narrow results of the investigation offer considerable optimism for greatly increasing the effectiveness of present science curricula.

At a larger scale, the investigation was designed as a test of the Amalgamated Model, and as such, the Model withstood the test: it was not disproved. The Model provides a framework within which our entire approach to science education could be fundamentally re-designed according to how children learn intellectually. Besides the treatment of energy concepts, there are many other implied changes that would certainly have a multiplier effect on the learning outcomes of students. All three aspects of the classroom, curriculum, instruction, and evaluation, would change considerably. The computerized database would provide researchers with a source of detailed, voluminous, real-time data on all three aspects of the classroom. Thus the Model, which would certainly evolve over time, provides an objective, quantitative approach to the research and development of science education in which both practitioners and researchers would contribute equally. Then science education would itself become a science.

The total effect of the changes would be radical enough that national policy makers would necessarily be involved. For example, the database of lessons and materials would ideally be networked at a national level that connected many regional nets operated from local colleges and universities.

The implementation of the Amalgamated Model finally rests upon two recommendations:

1) Science curriculum standards be defined in terms of a conceptual structure. The concepts are organized according to the three parameters of generality, complexity, and abstractness. Quantitative research be used to map the conceptual structure. Teachers may choose how best to have their students "climb" the structure within broad limits set by coordinating with other grade levels.
2) The content and process dimensions of the classroom, but especially the content, be left to teacher discretion. In order for teachers to accommodate these dimensions to student needs, interests and skill levels, they should be provided with access to a computerized, networked database of classroom lessons and materials that are indexed according to detailed educational criteria. In particular, to the concept being taught.