Socio-cultural Foundation of Mathematics and Science Education

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For the first half of this century, Mathematics and to a lesser extent Science, have practically ignored Anthropology. Except for a few examples of algebraic structures drawn from kinship relations, and which served to reinforce the prevailing idea of Mathematics as a universal, basically aprioristic form of knowledge, no reference to Anthropology, not even to Cultural Anthropology, appears as of interest to mathematicians. They might have said that this was because Anthropology was not relevant to a purely intellectual construction. Mathematics and Science Education were also biased toward primarily the technologically advanced, economically developed, politically structured and stable societies, where wage-labour and identifiable class structure were prevalent. Recognition of alien educational structures and different cultural modes were ignored. Research has been dominated by statistical models.

In recent years, however, many factors have found their way into Mathematics and Science Education and eventually will get into Mathematics and Science themselves. The acceptance of technologically backward, economically undeveloped, politically unstable and even unstructured societies, even lacking wage-labour and identifiable class structure, as fully independent nations, with long range goals and educational system of their own, and not merely the colonial model for colonialist purposes, brought into relevance the basic goals of Education in particular Mathematics and Science Education for all. Universal literacy became the goal for all the countries and a step further, which is scientific literacy and technological awareness is labeled as essential to cross the barriers of undevelopment in developing countries and to achieve full citizenship in developed countries. The emergence of new political rivalries, of new religious cults and indigenous movements of self-expression has permeated otherwise culturally and ideologically stable nations, and provoked reflections about established and apparently unchallengeable forms of knowledge, such as Mathematics. This is a particularly interesting case study.

All this has had influence in the development of Mathematics as scientific subject a particular in the transmission of mathematical knowledge, hence Mathematics Education. Mathematician's and philosopher's conceptions about the nature of Mathematics lack the empirical basic. While these sciences have been strongly influenced by changing views of the world

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resulting from the ceaseless discovery of new lands, new societies, new species, new "heavens", which grew together with technological progress, which is the cherished child of this same process did not leave room for critical views on it. The visions of History of Mathematics are always written from a "vainqueur" viewpoint and lacks the social dimension which my throw light into the very nature of mathematical knowledge. This was anchored on an overall misleading conception of cognitive process among mathematicians. The explanations for the mind-body relation have always pointed towards a dichotomic viewpoint, and this impulse to draw dichotomies is strongly present in the work of René Descartes, the first major philosophical writer on western rationality. Later on, rational analysis of the discourse stressed marked distinctions between emotive and cognoscitive forces in linguistic expressions. Mathematics is impregnated of decision-making, but the approach to mathematical thinking has mistakenly been characterized as a process of discovery, i.e., problem-solving form its own body of knowledge, through the inductive-deductive method. Instead, decision making and the abductive stage which permeates such a mode of thought, already pointed out by Charles S. Peirce in the turn of century, is identifiable in the process of mathematical creation and in the very nature of mathematical Knowledge, as has been recently pointed out by the excellent study of Philip Kitcher (Kitcher, 1983).

Also, the major reshaping of Western thought which took place in mid-XIX century by the works of Karl Marx and Charles Darwin, completed by the fundamental views of Sigmund Freud in the turn of the century, did affect little the understanding of the nature of mathematical knowledge. The search for rigour, which characterized XIX-century Mathematics, helped to create for mathematicians a world in itself and this crystalized in the XX-century. Great innovative ideas came from outside the field, by non-mathematicians dealing with not enough rigorous mathematics tools. Of course, this influences the ground on which Mathematical Education has developed in this century.

This thought has spread to Science and Science Education in general. The search for rigorous foundations for Science, with the ideal of bringing it to mathematical rigour, which developed into coining the term "Exact Sciences", had also its impact in Science Education, which lost most of its experimental and empirical appeal in favour of a theoretical treatment.

We are living through a period of challenge of this approach in Mathematics and Science Education, and this paper proposes the theoretical fundamentals for renewed, reality-oriented, approach to Mathematics and Science Education. For the sake of becoming less repetitive and coherently with our view of mathematics as a codified system of knowledge, we will avoid repeating Mathematics and Science. While using only the word Science, we understand Mathematics is included in Science. When there are specificities, we will mention Mathematics explicitly.

Science, recorded since Western classical antiquity has played a prominent role in Greek civilization and is in the sources of rationalism, which is considered practically unmatched, as the main root of modern science and technology. This led to the building up of the now universal model of an industrial society. The most critical period in the history of Western Education, which were the invention of writing and the adoption of Hindu-Arabic number systems, has a lesser dramatic and global effect in society as whole than the period we are living through, with both the emergence of what might be called the electronic era, and the profound changes bound to happen in the social, political and economic texture of the world. Through the universal concept of mass education in a fast-changing world, Science for all reaches an unprecedent dimension as a social endeavor and it makes it urgent to question, in a much deeper and broader way than before, the place of Science Education in societies as a whole, as well as its socio-cultural roots. Being in such a privileged position in Western thought, Science may be, at the same time an essential instrument in building up modern societies and a strong disrupting factor in cultural dynamics, as well as a strong instrument in the unbalancing factor which treatments the needed equilibrium between those who have and those who have not, which has to be achieved if we want to look at our species as behaving in a more dignified way than it has been in its long history. If we hope for a better world, without human beings massively exploiting and killing each other, we have to look into the role of Science Education in bringing up a new human dimension into the relations between individuals, societies and cultures. We have to deal with the urgent task of bringing socio-cultural dimensions into Science Education.

This paper is based on an analysis of the vast literature on human behavior and reflects work carried on for a couple of decades, in diverse cultural environments, with special reference to the perception of phenomena and efforts of its understanding and control through natural abilities, including the manipulation of traditions in everyday life.

When we say perception, abilities and manipulation, we are placing ourselves in a position of looking at reality, as perceived by individuals who use their abilities, in the form of strategies, to perform actions which invariably have their results in modifying reality. Hence, we are talking of human behavior as a cyclic model connecting reality-individual-action as characteristic of human beings.

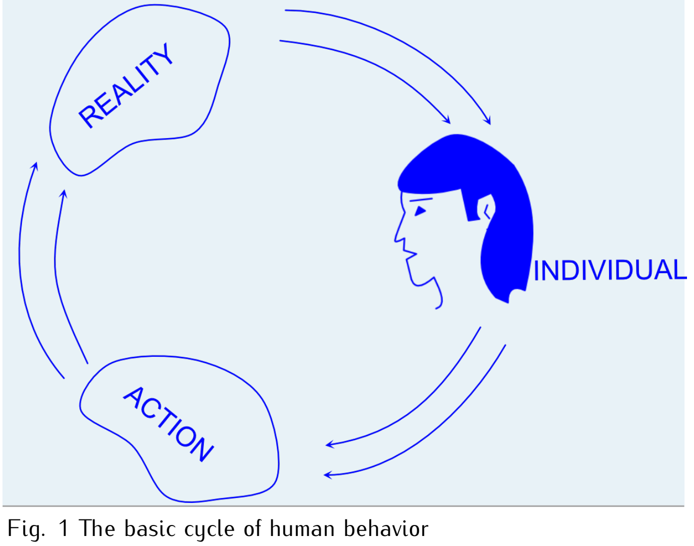

Fig. 1 The basic cycle of human behavior

We speak also of an hierarchization of human behavior which goes from the individual, to the collective (or social) to the cultural behavior, and finally to cultural dynamics which is the result of transcultural behavior. Each of these hierarchical steps is characterized by an instrument of interaction between several individuals which can be easily explained in the context of cultural anthropology and which builds up to the human capability of reification and of languages uses, of education and of communication and information as the decisive steps in this hierarchization of behavior.

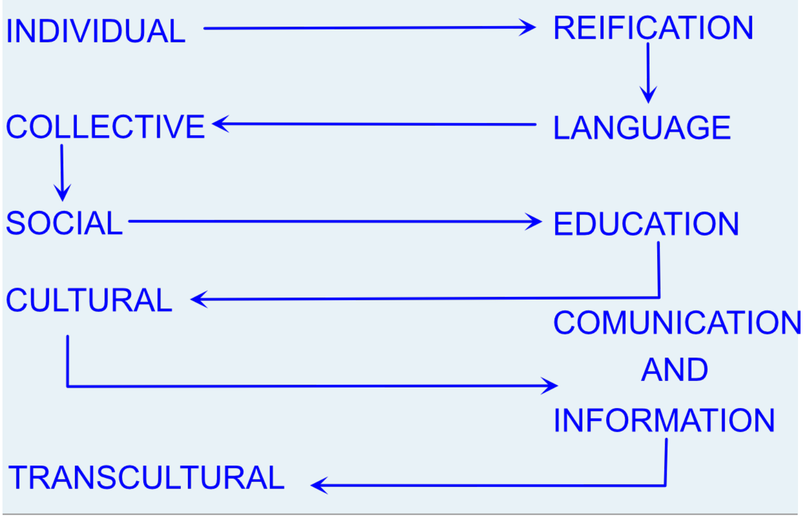

Fig. 2 Hierarchization of human behavior and the instrument of interaction

Children, as well as mankind, have an evolutive behavior in their learning which goes from individual to social and finally to cultural behavior. And we add transcultural behavior, which appears in an increasingly fast pace. Quite often a child raised in a rural area, moves to urban areas, which is most frequent in developing countries. The building up the new factories, new farms, new social benefits bring to different nations new patterns of behavior, a phenomenon which is increasingly seen in developing countries. But this happens equally in the most developed countries, which gives to this transcultural concept an important dimension in understanding the cycle reality-individual-action-reality.

This is basic in our conception of education as "action", which fits particularly in this cyclic model.

We also look into knowledge as action in the framework of the cyclic model which we used to characterize human behavior in its several hierarchizations: individual, collective, cultural and transcultural. Indeed, we have to understand which is the role played by knowledge in allowing human behavior to be thought as well as an action, which is impacted upon by reality and which brings about an action which modifies reality. We insist that action is inherent to human being, in particular to children. There are no still or inactive moments, if we understand action in its most general sense, be it a material or a purely reflective, intellectual, cognitive action. As far as there is life, there is action. We will return to this below.

Let us look into the effects of human action. Reality is in permanent change. Again, we talk of reality in a most broad and general way, both material reality or purely cognitive reality, that is, intellectual, psychic and emotional reality. We understand action as a modifier of reality in these very broad and general terms.

Now, let us look into human behavior and knowledge, also in the context of this cyclic model, allowing for an action which will have an impact upon reality. Since we know more, we can have mor influence as modifier of a reality. Children feel this as they grow. But in which sense are we using the concept of knowledge? What does it mean "to know" in this broad context of cultural dynamics?

To know has a dual sense if we look into the concept in several cultural ambiances. To know has always been understood as to clarify the cosmic and psychic order, which is "to know" in the most popular acceptance of the term, and which is in the root of the idea of science. But at the same time, to know is to create, to do something, which is in the root of the idea of art. This duality is well illustrated in the first four chapters of the Book of Genesis, which is an important tool in understanding the evolution of Western thought to what may be its most strikingly characteristic endeavour: Western Science and Western Art or Technic. And, of course, its brainchild, which is technology.

To understand cosmic and psychic order and to create are by no means dichotomic. They lead to science, which is a pure act of knowing, and to art and technic, which are acts of doing. Science does not materialize, in the same way as art never becomes art if it is not conveyed. This complementarity of science and art, which finds in technology its most impacting results, as far as the modern world is concerned, is indeed the complementarity of knowing and doing, of to know and to do. If one knows, one does, and to do you must know. This is a high level of consciousness of the individual, as "homo sapiens". Regrettably, much of the attempts to make children behave in a certain way have, in recent decades, disregarded this. This has had, in particular in Science Education and even more specifically in Mathematics Education, a damaging effect. Unfortunately, it is still going on. Although very worried about the course which society is taking, our main concern as educators is the individual, child or adult. And this individual is a complex of reactions, both sensual, rational and emotional or psychic. Even very small children have this complexity, what is sometimes forgotten among educators. And children are immersed in a reality. But which reality?

We have considered reality as both environmental, which comprises the natural and artificial, and intellectual, emotional, psychic, and cognitive, which is the very intimate abstract reality of ideas. Thoughts are part of a reality which impact any individual in a very intimate way , as well as emotions. And the individual is not alone, it is part of a society. Reality is also social. The interplay of the environmental, of the abstract, and of the social is a key issue in Science Education, again unfortunately often disregarded. The interplay of natural and artificial in building up environmental reality is probably one of the most critical areas in which Science Education has a major role to play. The equilibrium between natural and artificial has much to do with the future of mankind, hence with education, hence with Science Education. Environmental equilibrium deserves a special concern of Science educator, and fits perfectly well into the cycle reality-individual-action-reality.

Let us return to the concept of knowledge as action which involves the perception of reality, through the senses and through memory, which involves performing actions through strategies and models, and which causes modifications of reality, through the introduction into reality of objects, of things, or ideas.

There are results of the action of individuals which have an impact upon reality. They are incorporated into the reality in which every individual is immersed. Through the mechanisms of the senses together with the emotional-which we call the sensual-and through memory, individual is led to design strategies and models for action.

This comprises, in a global way, what has become known as art, technic and science as modifiers of reality, and the mechanisms of information and codification. Although art, technic and science have been the traditional domains of education, we want to concentrate a little more on information and codification, which indeed converge to give to knowledge the possibility of action. Information in this sense, which does result in bringing to the individual, through the mechanisms of the senses and through the information mechanisms which are the essence of what we call memory, both genetic and acquired memory, impacts from reality, to me is the crux of what is going on in education. Let us relate information and education, what seems to be particularly appropriate in the era in which we are living, where information, through the concept of informatics, has become a key issue. But we will talk of education, both formal and non-formal, which is education taking place in school environment and in out-of-school environments.

There, let us recall that information has gone, in the course of history, through an evolution from the spoken language to the written language, and to the more technological models of disseminating information through printed material and through electronics, which indeed is a joint process of information and processing information. Formal education is still dominated by written material and printed material, while non-formal education has domineering role in helping individuals to speak in the modern world, mainly through the media, in generating skills and in absorbing processed information. This is particularly important in Science Education and it seems to be urgent that we bring our formal education to recognize the increasing pressure of our society for information processing devices and technology. This is probably the greatest challenge Science educators still face in both developed and developing countries.

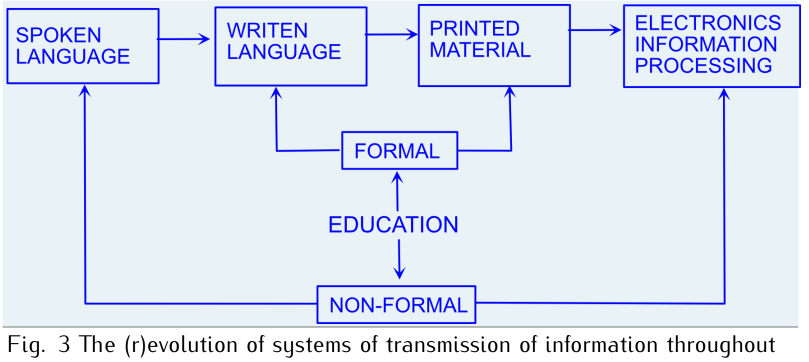

Fig. 3 The (r)evolution of systems of transmission of information throughout history of mankind and children development.

A full understanding of the evolution of the mechanism of Information Systems both in the history of mankind and in the evolution of children, seems to be decisive if we want to look into the relationship between and curriculum.

Education has its key strategy in the curriculum. We adopt a concept of curriculum which brings into consideration the classical objectives, contents and methods, but in an integrated way. It is impossible to consider each one separately and probably the main reason for the many failures identified in the so-called "Modern Math" movements has its roots in the breaking up of curriculum components into independent domains of research.

Curriculum, as it has been agreed without dissent, should reflect what is going on in society. Curricular dynamics always asks "Where" and "when" does a certain curriculum take place, and the key problem in curricular dynamics is to relate the societal moment, time and locality, to the curriculum, in the form of objectives, contents and methods in an integrated view.

But the societal moment is mor than simply time and locality, or when and where. I bring to the picture an extra dimension, of a much mor complex nature, that is cultural diversity. Same place, same instant, different cultural background makes the situation entirely different. In a same classroom a child coming from a family of working parents, or a child coming from a family of a professional father and a non-working mother, have completely different behavior to certain issues. Even more when there is different ethnic background, which happens so often in both developed and developing countries. The big challenge I see in education, in rapidly changing societies, is how to bring this cultural diversity into curriculum design. This is particularly true when we look into Science as a subject for all in rapidly changing societies. In other words, the key issue in curriculum design for the years to come seems to me to be to meet this challenge.

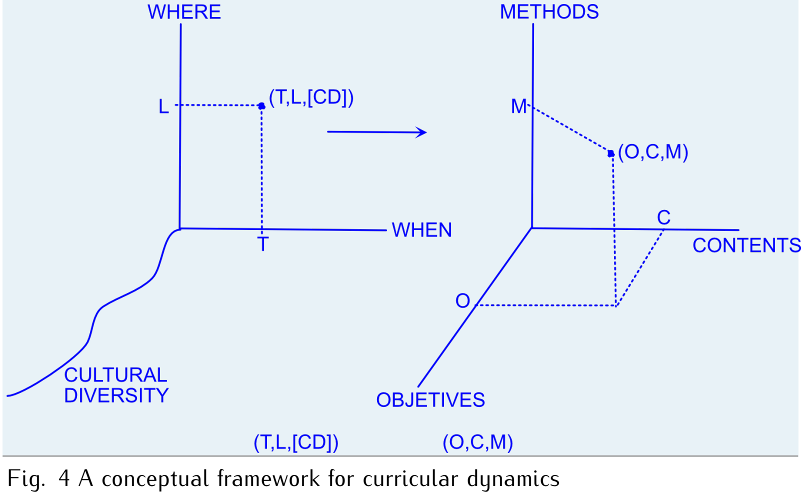

Fig. 4 A conceptual framework for curricular dynamics

Cultural diversity is so complex, it is like a mesh of attitudes and behaviors which have not been sufficiently understood in education, and specially in Science Education. I would dare they have practically never been recognized as important factors in Science Education. Attitudes such as modes of thought, jargons, codes, interest, motivation, myths, build up to generating very definitive cultural roots, modes of production, modes of property, class conflicts, sense of social security, human rights and so on. These are factors which compose society, but are usually ignored in Science Education.

We are now faced with a concept of society which grows from individual behavior, and which is the key issue in our recent concerns about Science Education, that is the relationship between Science and Society.

But we go further in these considerations. Our considerations above depend on a concept of society out of cultural attitudes and cultural diversity, that is, different groups of individuals, who behave in a similar way because of their modes of thoughts, jargon, codes, interests, motivation, myths are groups, into a cultural frame. They constitute what we call societal groups, which clearly defined cultural roots, modes of production and property, class structure and conflicts, and senses of security and of individual rights. All these constitute societal background for children. Several studies have been conducted on the social behavior of children, which allows for identifying what we might call "children's societal arrangements". We are also concerned, in Science Education, whit this level of society, which is the ground on which we work, as well as with societies in the general sense. These vertically hierarchized societal levels have, as a result of the interaction of their individuals, developed practices, knowledge and in particular jargons -the way they speak- and codes, which clearly incompass the way face nature, that is the way they count, the way they measure, the way they relate and classify, the way they infer, the way they explain phenomena. This is different from the way all these things are done by other cultural groups. Hence, we have the question, in dealing with the relationship between Science and Society: which Science? Are we interested in the relationship between learned Science and society, or between "ethnoscience" and society, where "ethno" comes into the picture as the modern and very global concept of ethnicity both as racial and/or cultural, which implies language, hence codes, symbols, values, attitudes, etc., and which naturally implies scientific and mathematical practices?

We will look more carefully into this concept of ethnoscience and the practices associated with it in this context.

These are practices identified with cultural groups, and which are transmitted taught, perfected, reflected upon, through a non-formal education system. These practices are not designed "ad hoc". They are the result of accumulation of knowledge and experiences of many generations. It has the characteristics of cumulative knowledge. We could easily multiply examples with situations drawn also from developed societies, even from industrial and commercial environments.

Let us recall that we call Learned Science the body of knowledge which is taught in our schools. Let us look into the ways Learned Science feeds itself with new knowledge., mainly in the course of Science curricula in schools. It is indeed a closed body of knowledge, feeding itself with ideas taken from this same body of knowledge, while society has little or no influence in the evolution or building-up of scientific knowledge. In other terms, innovation, which is a key element in education, in particular in Science Education, practically ignores the results of the evaluation of scientific practices vis-à-vis of societal impact. In other terms, in talking of Learned Science, evaluation of the impact of what is learned upon societal activities has practically no effect on innovation, or in the cases there is an effect, there is an enormous time-lag in this interaction. Of course, keeping alive the interest of children in new ideas, new concepts, and innovation in general, is a very difficult step, making the results far from satisfactory. The enormous time-lag works against motivation. On the other hand, ethnoscience shows an almost inexistent evaluative barrier with respect to society, it is like a porous system with permanent interaction.

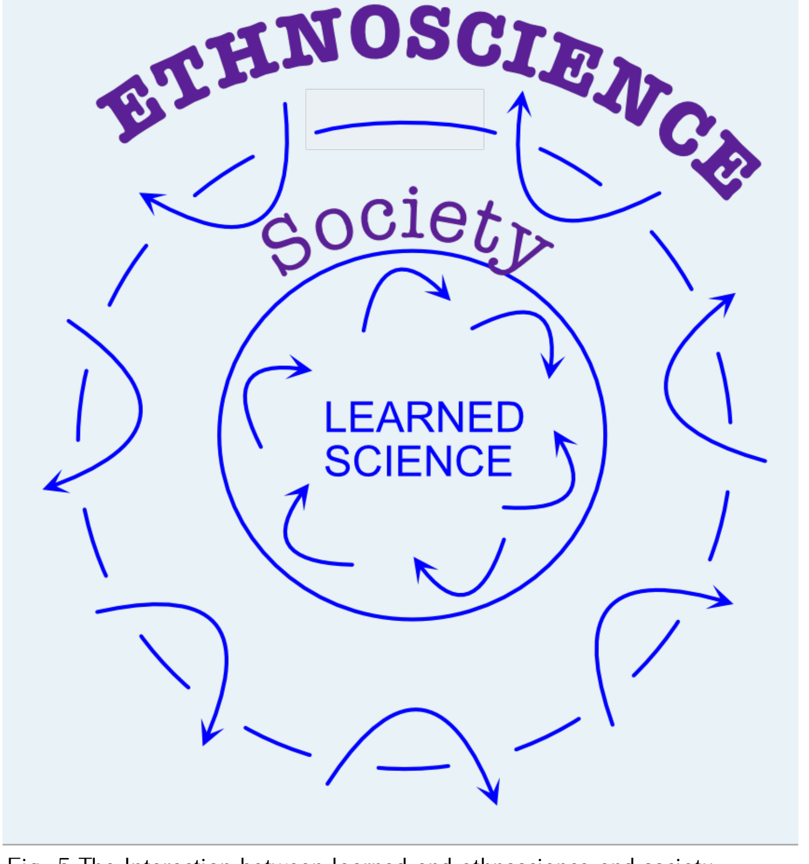

Fig. 5 The Interaction between learned and ethnoscience and society.

Evaluation of what is the result of an ethnoscience practices results from immediately changing it into societal practices, which in turn feeds the body of knowledge, int this case ethnoscience, with innovation. In other terms, the relationship between ethnoscience and society is characterized by fast reaction, through a self-regulating system. This self-regulation system manifests itself in the building -up of motivation, an essential component in education. Indeed, this self-regulating system activates the basic cycle reality-individual action-reality upon which we have based our remarks on Science Education and a more dynamic relation of it with fast changing societies. It seems to me that to generate this dynamic is the key issue in Science Education in the years to come.

Bibliography on ethnoscience is beginning to buildup. It seems the concept was first mentioned explicitly by the author in 1977, with a definition: "ethnoscience devotes the study of scientific and, by extension, technological phenomena in direct relation to their social, economic and cultural background'' (D'Ambrosio, **1977**, pp. 267). More recently, a close connection between ethnomathematics and cognition in Mathematics, was analyzed in (D'Ambrosio, **1985a**, **1985b**, **1985c**). The book by David F. Lancy (Lancy, **1983**) seems to be one of the first systematic account on research on cross-cultural cognition in the field of Mathematics. Also, it is quite important the research conducted by Jean Lave on cross-cultural cognition (Lave, **1982**). And finally, we mention a recent book by R. Pinxten, I. van Dooren and F. Harvey which explores into the Natural Philosophy and Semantics of the Navajo (Pinxten, Dooren and Harvey, **1983**).

Far from covering what might be labelled as ethnoscience, these references are only an indication of possible areas of research in this field.

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