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RESEARCH ARTICLE

COGNITIVE DEVELOPMENT IN CHILDREN, HISTORY OF SCIENCE and THEORY CHANGE IN SCIENCE.

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Abstract

Conceptual change is a significant component of all major changes of theory in science. The process of scientific concepts and of theory development in science seems similar in nature to the knowledge acquisition of biological concepts during childhood. Susan Carey has developed several information-processing methods of investigating knowledge acquisition of biological concepts in children. According to Carey, knowledge acquisition of biological concepts is a transitory process characterized by differentiation, coalescence and a shift from property to relation among concepts between 4 and 10 years of age. By comparing these models and one of the major methods of investigating conceptual change in science, called a cognitive-historical method which combines imagistic and analogical reasoning which has been developed by Nancy Nerssesian, it is plausible to argue that Carey' s methods are better in explaining the nature and the process of conceptual change in scientific theories.

Introduction

Throughout the history of science, older theories have undergone some changes or been replaced by some other theories. The logic and nature of theory change has been an important issue among philosopher-historians of science. There are different views concerning how scientific development occurs. Traditionally, great scientists throughout the history of science take science as a cumulative phenomenon, which develops, by breakthroughs. Recent philosopher-historians of science have come to an agreement that the rationale of scientific development is not disclosed by a mere description of the temporal sequence of great episodes in the history of science, but is uncovered by a careful determination of the conceptual changes, as mapped onto a received tradition and available bodies of evidence.

This new emphasis among the philosophers of science depends on the thesis that scientific change can effectively be explained only by conceptual changes within theories. Conceptual changes are important components of all major changes of scientific theories. Theory change can be explained by means of conceptual change in theories. In her book, *Science and Philosophy*, Nancy Nersessian argues for a reconstruction of scientific concepts. Theories just do not arise in some "creative leap"; rather they are constructed from a changing network of beliefs and problems.

This process of reconstruction of scientific concepts and of theory development in science seems similar in nature to the knowledge acquisition of biological concepts during childhood. When we look at the cognitive development of children, we see that learning a specific concept and starting to use it is a progressive process such that as the child grows older, the concept becomes more complex and abstract, while at first, it is concrete, primitive and non-specific. An interesting account of conceptual development in children can be found in Susan Carey' s book, *Conceptual Change in Childhood*. Carey states that preschool children lack adequate knowledge of basic biological concepts, and that this is what creates the incommensurability between childrens' and adults' conceptual processes. According to her, during the years 4 to 10 in childhood, the child' s knowledge of animals and living things undergoes a restructuring process. She claims that, this restructuring process is very likely of the stronger sort[i] that must be taken as full-fledged theory change, involving conceptual reorganization. Carey uses several models to show and explain the restructuring of the child' s knowledge about animals and living things.

It is the task of this paper to investigate whether one can apply the models of conceptual change discussed in Carey' s work to theory change in science. We will argue that such an account is possible. The comparison of models suggested by Carey to the cognitive-historical method, which is developed by Nersessian in order to explain conceptual changes in theories, supports our thesis. Nersessian uses the concept "electromagnetic field" as an example in her theorizing. When one investigates changes that the concept of "electromagnetic field" undergoes from Faraday' s concept of field and his theorizing to Einstein' s relativistic interpretation of the concept "field", and the nature of changes between these two theories, it is seen that this process of transformation is better accounted by Carey's models.

In order to make a better comparison; first of all, the concept of theory change should be clearly defined. In the history of science, theory change can be recognized as being one of the following kinds, one is changes that a theory undergoes within itself, which can be called true theory change, and the other is the emergence of a new theory. In true theory change, a well developed domain of study undergoes revolution, as in the transition from the impetus theory to Newtonian mechanics or from Newton' s theory to Einstein' s. In the other, a new theoretical domain emerges from a parent domain, as the new domains of evolutionary biology, logic, psychology, and chemistry emerged in the nineteenth century. Carey (1985) claims that these two different approaches to theory change can be reduced to each other:

Even theory emergence involves true theory change. Insofar as the new domain overlaps with older theories, thew changes in explanatory framework and concepts constitute true theory change. That is, the phenomena in the domains that overlap are reconceptualized and are articulated in terms of new concepts (p. 5-6).

According to Carey, children's concepts of biological, physical and social world changes and differentiates, as the child grows older in a similar process of changes in scientific theories. As can be seen from the above quotation, a change in a scientific theory should be understood not as replacing old concepts with new ones, but rather, as changing the explanatory frame of the concept. Such an approach requires thinking and analyzing changes in the concepts that a child has and changes in theories in similar ways. These changes in theories consist in changes in explanatory principles and changes in domains of phenomena accounted for. Similarly, cognitive development consist, in part, in the emergence of new theories out of older ones that the child has already had, with the accompanying restructuring of the ontologically important concepts and emergence of new explanatory notions.

Then, the reorganization process of biological knowledge that occurs between ages 4 and 10 may be thought to be as the same kind of process as theory change. In Carey's account of knowledge acquisition during childhood, one can make a connection between domain specific knowledge acquisition in children and adults, and changes that theories undergo in the course of time. The process of knowledge acquisition in a particular domain is structured differently in young children and adults. Concepts such as size, weight and density become elaborated as children gain more knowledge of them as they grow, and finally reach to their adult conception. According to Carey' s interpretation, the process of restructuring of knowledge seems to have a similar mechanism both in the process of domain specific knowledge acquisition in children (Carey especially considers acquiring knowledge about biological concepts) and the process of theory change in science.

Susan Carey develops several models to explain how knowledge acquisition of biological concepts differs between children and adults. There are mainly two models she takes under consideration. One of these models is an information-processing model, which mainly consists of three different types, namely deductive inference or direct representation, application of definition, and similarity to exemplar, and the other is a quessing model. Let us proceed to examine what these models account to.

Information-Processing Models:-

Carey seeks to constrain a model of how children answer questions such as "do snakes breathe?" She thinks that information-processing models can explain these kind of questions better and more accurately than other models because in order "to answer a question such as 'do snakes breathe?' children must combine information they have represented about snakes with information they have represented about breathing" (1985, p. 75).

She distinguishes three classes of models under the heading information-processing model. These are:

Model Type I (Deductive Inference or Direct Representation)
This class of models is characterized by deductively valid inference. "In this class of models the only knowledge of a given property (say, breathing) available to the child is his or her current knowledge of which things have the property in question" (1985, p. 75).

Model Type II (Application of Definition)
In this class of models the child retrieves a definition of the property in question. The object is then examined with respect to applicability of the definition. Hence, "the key to models type II is the characterization of children' s definitions and of the process by which they apply them to the objects in question. The child' s definitions might be couched in terms of human activities these properties represent. For example, sleeping can be seen as lying down, closing one' s eyes, and losing consciousness for a period of time". Then, the decision whether some other object has one of these properties would include checking for the activities of people mentioned in the definition (1985, p. 75).

Model Type III (Similarity to Exemplar)
"In this class of models the relevant knowledge of the property in question (say, breathing) is an exemplar of things, which have that property. For example, the child might retrieve the information that people breathe, or that dogs do, or that fish do. She, then, compares the animal in question with the retrieved exemplar, and makes a judgment on the basis of the similarity of the two (1985, p. 75).
Carey, after evaluating all three classes of models in the light of the data she has gotten from her experiments investigating the knowledge acquisition of the biological concept of animal in children, decides that the third model, namely similarity to exemplar, plays a major role in children's judgments about properties animals have. She claims that in many of their judgments, children do not possibly use deductive inference because they attribute properties of known animals to animals they have no direct knowledge of, or they have never seen. If this process was a process of deductive inference, then it would have depended on a general claim such that all animals have the property in question which is certainly not the case here. A similar situation is also observed in the case of application of definition. The application of definition model can easily be considered in terms of the similarity to exemplar model, since the decision whether some other object has one of a given set of properties would inevitably include checking for the activities of people mentioned in the definition.
Moreover, the lack of differentiation among the attribution patterns for the different properties is predicted the model type III (comparison to people) whereas other models fail to predict this (1985. P. 87). The interaction among these three types of models constitutes the information-processing model.

Guessing Model:-
Carey also suggests a guessing model besides information-processing models. According to this model, unless they definitely know the answer, children simply guess. "The guessing model can be combined with any of the three types of information-processing models which are distinguished on principled grounds; whenever some threshold of certainty is not crossed, the child guesses" (1985, p. 76). Even though children in their judgments frequently use guessing, the data collected from various experiments also support the third model, namely similarity to exemplar, over the guessing model.

After viewing the models Carey uses to explain the incommensurability between children's and adults' conceptual systems, and acquisition of biological knowledge between ages 4 and 10, now, let us proceed to examine the relevance of these models to conceptual change in theories in science.

Conceptual Change In Theories And Information- Processing Models:-
There is a contrasting difference between models underlying the projection patterns (projection of information about some given animal to other animal – nonanimal things) of 4 year olds and adults. The difference between the models underlying adults' and children's projection patterns is due to the differences in their biological concepts and knowledge acquisition. "Adults understand that internal organs have evolved to solve the biological problems [and] in making their decisions, they rely on category membership and detailed knowledge of biological properties". (1985, p. 161). In contrast, young children do not understand the function of most internal organs. "They certainly do not have an articulated idea of what general biological problems must be solved by all animals, and what common solutions nature has evolved" (ibid. p. 161). Thus, children' s judgments about biological phenomena such

as eating, breathing, sleeping do not depend on adequate biological knowledge of these concepts; rather, children think of these activities as voluntary human actions and in their judgments about them, they rely mainly on similarity to people.

According to Carey, these data from patterns of inductive inference provide an evidence of conceptual organization. She claims:

Preschool children do not know the relations between eating, breathing, having a hearth, and so on, in supporting life; nor do they realize that all animals must eat, breathe, and have babies. They conceive of these processes as part of intentional human behaviors, and explain them in terms of what the person (or animal) wants and thinks. By age ten, in contrast, children have constructed a first theory of the human body, and understand that bodily processes underlie the functioning of all animals (ibid. p. 112).

Thus, in Carey's account, between ages 4 and 10, a new framework for understanding people in terms of their biological structures begins to emerge. The conceptual reorganization that plays a role in this process of emergence of a domain of knowledge thus involves both the concept animal and the concept living thing. This new framework in which both of these biological concepts (animal and living thing) come to play a central organizing role can be called intuitive biology.

This intuitive biology also depends on an intuitive theory of behavior, which Carey aptly calls naive psychology. It is called naive psychology since it is mainly concerned with human behavior, and since it explains behavior in terms of wants and beliefs. Activities such as eating, sleeping, breathing, dying, growing, being a male or a female and having babies are part of the domain of human activities that concern with continuity and preservation of its life as a living thing. For the young child, though, these are phenomena of the same sort as activities such as playing, bathing and talking. The explanatory structure in which these latter phenomena are embedded is social and psychological. The whys and wherefores of these matters, as the child understands them, include individual motivation (hunger, tiredness, avoiding pain, seeking pleasure) and social conventions. Thus, a 4-year-old child's explanation of these basic biological concepts is in terms of psychological and social factors. Then, obviously the cognitive schemata of 4 year and 10 year olds differ from each other in explaining biological concepts such as eating, breathing, internal organs, and so on; while the explanation of 10 year olds depends on biological concepts, 4 year olds depend heavily psychological and behavioral considerations.

The nature of this difference in the cognitive systems of 4 and 10 year olds is similar to the process of theory change in science. As the process of acquiring biological knowledge changes and become more elaborated by age, in a similar mechanism, both the domain specific knowledge and explanatory schemata of a scientific theory changes in the course of time, and this change constitutes the process of theory change. Thus, the changes in both domain and explanatory structure characteristic of theory change are exemplified in Carey's study.

In their descriptions of knowledge acquisition, developmental psychologists and philosopher-historians of science alike appeal to changes at the level of individual concepts. One of the most attributed forms of change at the level of individual concepts is *differentiation*. According to Carey, there are, of course, other kinds of change at the level of individual concepts, namely, *coalescence* and the *shift from property to relation*. "In the history of science, before the time of Black, heat and temperature had not been distinguished from each other. Similarly, in Aristotle's physics the concepts of average and instantaneous velocity were conflated under one concept of velocity" (1983, p. 268). She also gives several examples of coalescence. "In Einsteinian mechanics, the Newtonian categories of gravitational and inertial mass are collapsed into a single category. Similarly, Galileo collapsed the Aristotelian categories of natural and violent motion together, seeing that the distinction did not correspond to a real difference in nature" (ibid. p. 268). As an example of the shift from property to relation: "before Newton, weight was thought of as a property an object had intrinsically, i.e. independently of other objects. But in Newtonian mechanics, an object's weight involves a relation between itself and objects that exert a gravitational force on it" (ibid. p. 269).

We can easily correlate this picture of changes at the level of individual concepts in theories in science to biological knowledge acquisition in children. Differentiation of two senses of *not alive*, dead and inanimate and also differentiation of concepts of weight and density or weight and size between ages 4 and 10 are similar in nature to the differentiation of heat and temperature or instantaneous and average velocity physics. When such distinctions are finally made, conceptual differentiation has taken place. Similarly, coalescence of animal and plant under the concept living thing between ages 4 and 10 requires the same kind of conceptual change as in physics when the two senses of natural and violent motion in Aristotelian physics were collapsed into one concept of motion in Galileo's theory. The discussion of changes at the level of individual concepts – differentiation and coalescence – reminds both the process of reorganization of a domain-specific knowledge in theories in science and the process of knowledge acquisition of biological concepts in children.

Carey's work suggests that formulating and evaluating hypotheses develop in two different ways during childhood. When these development patterns of children are investigated, it can easily be seen that the strategies that children develop in making sense of the world are quite similar to the processes scientific theories use in explaining phenomena. In the first one, the child elaborates conceptual systems that license more sophisticated hypotheses and encompass wider classes of phenomena as evidence of the evaluation of these hypotheses. This is acquisition of particular domains of biological knowledge. In the second, the child can engage in hypothesis formation and evaluation more consciously. This is the acquisition of metaconceptual knowledge. In children, concepts such as density, size, weight, velocity, time, space become elaborated in the course of knowledge acquisition; the child evaluates and changes the concepts s/he already has in the light of new information. This means that theories in a child's mind which have developed to explain phenomena change by means of changes that occur in basic concepts of these theories. As can be seen from this description, theories whether in a child's mind or in science change when they fail to explain or predict phenomena.

Nancy Nersessian, on the other hand, applies a different method, namely a cognitive-historical method, to explain conceptual change in theories in science. In accordance with her method, Nersessian makes use of imagistic and analogical reasoning in the explanation of the construction of scientific representations. Now, let us proceed to discuss Nersessian's account and try to draw some connections between these two accounts of conceptual change.

Conceptual Change ın Theories and Cognitive- Historical Method:-

Nancy Nersessian, in her book *Science and Philosophy,* argues that scientific concept formation is a process and that conceptual change in theories can be best explained by changes in a network of beliefs and problems. She introduces the notion of "meaning schema" for scientific concepts as a key notion to analyze the process of concept formation. According to her, " a 'meaning schema' for a particular concept contains within it key features of that concept at each phase of its development, with the reasoning process from one phase to thenext supplying the *co*nnection between earlier and later forms of a concept" (1984, p. xii).

Thus, in her discussion of the formation of the present concept of electromagnetic field from Faraday's "lines of force" to Maxwell's "Newtonian ether-field", to Lorentz's "non-Newtonian ether-field" and finally to Einstein's "independent reality", Nersessian focuses on the beliefs and problems which led key features of that concept at each phase of its development, with the reasoning process from one phase to the next supplying the connection between earlier and later forms of a concept" (1984, p. xii).

Thus, in her discussion of the formation of the present concept of *electromagnetic field* from Faraday's "lines of force" to Maxwell's "Newtonian ether-field", to Lorentz's "non-Newtonian ether-field" and finally to Einstein's "independent reality", Nersessian focuses on the beliefs and problems which led to the various changes in what is meant by *electromagnetic field*.

Nersessian, similarly, argues for a transition of successive theories in science, and connects conceptual change in theories to a reconstruction process of scientific reasoning:

Conceptual change is an extended process. From fine-structure analyses of the periods of transition, the more complex characterization emerges. The difficult task for the philosopher of science is to provide an explanatory account of the continuity and discontinuity found in actual conceptual changes in science. A critical dimension of this task is to formulate an understanding of how new conceptual structures are constructed. The cognitive part of the method has its working hypothesis that scientific conceptual structures are representations of the external world constructed by the minds of scientists. . . Thus, a full understanding of conceptual change as it occurs in science requires bringing our account in line with the reasoning processes and the nature of representations used by cognitive beings (1989, p. 4).

As can be seen the passage above, the aim of the cognitive-historical method is to be able to reconstruct scientific reasoning using cognitive theories. According to Nersessian, examination of actual cases of concept formation in science, establish that concepts do not emerge fully grown from the heads of scientists, but are constructed in attempts to solve specific problems by utilizing specific procedures such as analogical and imagistic reasoning.

Nersessian, in her application of the cognitive-historical method to conceptual change in theories, uses, imagistic and analogical reasoning in the creation of new scientific concepts. She is particularly interested in the reconstruction of the concept of *electromagnetic field*. She takes analogical reasoning as a basic and central reasoning process in the construction of a new scientific concept. She claims that one of the most important cases in the history of science where analogy has played a central role in the construction of a new scientific concept is Maxwell's use of analogy in formulating the concept of *electromagnetic field*.

Some other examples in which analogy has played a role in the construction of a new concept are as follows: "Newton's analogy between projectiles and the moon (universal gravitation), Darwin's analogy between selective breeding and reproduction in nature (natural selection), and the Rutherford-Bohr analogy between the structure of the solar system and that of the configuration of sub-atomic particles (atom)" (ibid. p. 8). She argues that no current cognitive theory is comprehensive enough to handle all the complexity of the Maxwell's account. What is known about analogical problem solving supports her position that a specific analogy has generated the key elements in the solution to the problem of finding a field representation for electric and magnetic forces. As for imagistic reasoning, she considers it as a form of analogical reasoning.

Nersessian, in her search for the construction of the meaning of the field concept uses imagery and analogy as a part of the cognitive-historical method. Her aim in doing this is "to provide some of the networks of methodological, theoretical and metaphysical beliefs of each scientist considered, namely, Faraday, Maxwell, Lorentz and Einstein; to indicate the problems that figured significantly in the attempts to articulate a field conception of electric and magnetic forces; and to discuss what reasons were given for, or lay behind, each significant change in reasoning" (1984, p. 34).

The development of the concept of the field was as follows: First, with Faraday's "lines of force", the field is a physical state of stress and strain in space. The question as to whether or not space is filled with ether is left open, with Faraday leaning towards the view that the lines of force are themselves substances existing in mere space. Maxwell, however, interpreted the strains and stresses to be the states of a material medium. He conceived of the field as a state of a mechanical ether, i.e., one which obeys Newton's laws. In his fully developed theory, though, he acknowledged that it might not be possible to formulate an adequate mechanical model of ether, while at the same time, he held that the concept of field is essential to the description of electric and magnetic actions. Lorentz, while maintaining that the field is a state of ether, altered the nature of both. Lorentz's ether is a non-Newtonian substance. Finally, in asserting that the ether is "superfluous" and going on to establish why, Einstein put the field ontologically on a par with matter. That is, our present concept of field is that it is an irreducible element of description (ibid. p. 35).

Nersessian explains the construction of the field concept in terms of imagery and analogy. She argues that "Faraday was the first to attempt to construct a unified field representation for electric and magnetic actions", but his construction of the field was primarily qualitative and he heavily relied upon imagistic representations (1989, p. 9). According to her, even his choice of terminology reflects the effect of imagery in his reasoning such as "number cut", "expanding lines", "shaking", "bending", "vibrating", "turning corners" (1985, p. 146). Thus, for Faraday, all the forces of nature are unified and interconvertible through various motions of the lines of force. Maxwell, similarly, aimed to formulate a unified representation of electric and magnetic actions, but he combined imagery with quantitative reasoning in what he called "the method of physical analogy". Maxwell's use of physical analogies led him to construct a scientifically viable concept of electromagnetic field: "Electric and magnetic forces are propagated with the velocity of light in a Newtonian ether according to a specific set of equations" (ibid. p. 150). Nersessian notices the transition from Faraday's "mechanical analysis" to "dynamical" analysis of the field concept starting with Maxwell:

In Maxwell's third paper, treating the ether as a "connected system" made the transition from a "mechanical" analysis. So, with a mathematical formulation a dimension was added to the meaning of "electromagnetic field" that made it unnecessary to find out exactly what kinds of processes were involved before proceeding to the elaboration, clarification, and extension of the new concept. Maxwell's "dynamical" analysis masked the non-Newtonian nature of the system, which came to the fore in Lorentz's analysis. Despite its mathematical precision, Maxwell's field concept was still vague, not only with respect to the nature of the underlying processes; but also regarding the differences between ether and "ordinary" matter and regarding the nature of charge and its relation to the field. It was Lorentz'' endeavor to clarify these – from his network of beliefs and problems – which led to the derivation of the non-Newtonian "Lorentz's force" and to the subsequent non-Newtonian features of his "theory of electrons" (1985, p. 150).

A different network of beliefs and problems, on the other hand, led Einstein eliminate the ether. Given his analysis of space and time, the ether cannot function as a reference frame, and the causal role it played in Faraday's formulation was not needed in Einstein's conception.

In Nersessian's account, particular scientific practices, as exemplified above in each of the scientists' work in constructing the field concept, are deeply connected to the questions regarding meaning. As can be seen from the exposition of her work, for Nersessian, it is impossible to separate questions of meaning from the network of beliefs and problems which are the motivations behind the attempts in the construction of meaning. But she goes on to argue that even though there is a meaning variation from Faraday to Einstein concerning the field concept, there still is a "significant degree of commensurability" between these four different conceptions of the field concept. She holds such a view for the reason that there is a chain-of –reasoning that we can follow from Faraday to Maxwell, to Lorentz and finally to Einstein; and that this chain-of –reasoning connects these four different networks of beliefs and problems under one common concept – the concept of electromagnetic field.

Nersessian agrees with Carey in several respects. They both argue for an incommensurability of successive theories. New conceptual structures are not simply extensions of previous structures; the concepts of two different theories can neither be combined nor be translated into a common structure. But they have different methods for explaining theory change or, in other words, recognizing or restructuring concepts in theories in science.

Carey, while agreeing with Nersessian that the incommensurability of two successive theories arises from a changing network of beliefs and problems, she has a different approach to it. Carey argues that the kind of difference and incommensurability between language and conceptualization processes of children and adults is similar to the differences and incommensurability of the meaning of concepts between successive theories in science. She claims that these two phenomena have the same developmental pattern. Conceptual change between ages 4 and 10 marks the incommensurability of the network of beliefs that 4-year olds hold and the network of beliefs that 10-year olds and adults hold.

If we apply Carey's account to the process of change in the field concept from faraday to Einstein, we can see that there is a clear incommensurability between Faraday's theorizing and meaning of the field in his terminology, and the meaning of the field in Einstein's theorizing. Our thesis is that it is plausible to apply the models Carey has developed in order to explain cognitive development processes in children to the process of conceptual change in theories in science. Now let us examine the changes and differences in the meanings of concepts from Faraday to Einstein in terms of Carey's theory.

Information-Processing Models and The Construction Of The Electromagnetic Field Concept:-

As can be seen from our discussion above, there is a contrasting difference between theories underlying the field concept in Faraday's account and of Einstein's relativistic interpretation of the concept electromagnetic field. This difference might possibly be caused by each of the successive scientist's from faraday to Einstein holding a different network of beliefs and analyses. The construction the field concept has been changed from Faraday's mechanistic formulations to Maxwell's and Lorentz's elaborative and dynamic, and finally to Einstein's philosophical theorizing. This process of change in the field concept from Faraday to Einstein is similar in nature to the process of change in the models children and adults use in their judgments about animals and non-animal things.

Nersessian herself also admits the transition from Faraday's "mechanical " analysis to "dynamic" analysis of the field concept starting with Maxwell. This transition in the explanation and theorizing of the field concept can be explained in terms of the transition from an intuitive biology or what Carey calls naive psychology of 4 year olds to biological theory and thinking of 10 year olds and adults.

We can follow a similar pattern in the transition from faraday's theorizing to Maxwell and Lorentz, and to Einstein's theorizing. First of all, Faraday lacked the mathematical knowledge and background to support his concept of the electromagnetic field; he rather relied upon speculations, which made his account scientifically not very viable. He even did not use the term "field"; rather he talked about "lines of force". As already discussed above[ii], his choice of terminology also reflects the speculative and qualitative nature of his conception. Thus, with Faraday, we have the use of rather vague analogies, which provided him a way to begin to conceptualize how such actions could be transmitted continuously through space, along the lines of force. Having a different network of beliefs and problems, Maxwell, on the other hand, used very detailed and mathematically sophisticated "physical analogies" which acted as heuristic guides allowing him to explore the new conceptual possibility enabling him to derive the correct equations for the electromagnetic field concept. Maxwell's account marks the transition from the "mechanical" analysis of Faraday to "dynamic" analysis of the field concept. Lorentz, having a different set of beliefs and problems, established his theory of electrons while changing the nature of ether with the derivation of non-Newtonian "Lorentz force". Lorentz's conception of the field as a state of a non-Newtonian ether was a significant change in the concept and was influentual on Einstein's thinking. Finally, in Einstein's special theory of relativity, the field was no longer a state of an ether while it has the same mathematical structure as Lorentz's field concept.

As can be seen from the discussion of the construction of the field concept, while each successive scientist continues to work on from the point where the others have left off; they all have their specific and different set of beliefs and problems which shape their theorizing, and consequently, the construction the field concept. At the end, we can find almost no common point between Faraday's and Einstein's field concept, just as there is no connection between pyschological and social conceptualizations of 4-year olds and adults, and biological conceptualizations of 4-year olds and 10-year olds and adults also have no common points. Faraday and Einstein apparently have different conceptualization processes and different mechanisms of explanation — heuristic vs. philosophical, qualitative vs. quantitative, mechanical vs. dynamic — for the related phenomena.

Faraday's conception of the field was a unified field of force, in which all the forces of nature are transmitted through lines of force. Nersessian (1984) argues that Faraday coalesced this conception during his second period of research, in his attempt to formulate a conception of the continuous transmission of force in dielectic media. The reformulation of this conception is also explainable in Carey's account of knowledge acquisition. Faraday's coalescence of particles with their lines of force can be thought to be as a similar process to the coalescence of concepts animal and plant under one category of "living thing" between ages 4 and 10.
In short, in the period from Faraday to Einstein, the field concept had undergone a reorganization or restructuring process. One can see a similar pattern in restructuring of biological knowledge acquisition during childhood between ages 4 and 10, and restructuring process of the field concept.

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[i] Susan Carey distinguishes two different senses of "restructuring". One is the weaker sense in which with expertise, new relations among concepts are represented, and new schemata come into being that allow the solution of new problems and change the solution to old problems. The second, stronger sense includes not only these kinds of change but also changes in the individual core concepts of the successive systems. She mostly considers knowledge restructuring in the strong sense. Since all changes — differentiations, coalescences, changes in ontological commitments — are understandable only in terms of changes in domains and of causal notions between the successive theories, she asserts that, when all of these changes are found, that we should be confident that the knowledge reorganization in question is of the stronger kind, involving conceptual change (1985, p. 5-6).

[ii] See, p.7.