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From Cognitive Evolution to Cultural Evolution to Explain the Sustainable Development of Science: A Problem and Its Plausible Solution

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Abstract: From the perspective of human cognitive evolution to analyze the origin and sustained development of science, there is a puzzle, because the driving force behind cognitive evolution is natural selection, which favors biological traits improving individual adaptation rather than seeking the truth. Some scholars argue that cultural evolution provides an explanation for the development (or progress) of science, wherein scientific beliefs can be transmitted intergenerationally within the scientific community, thus continually converging toward truth. However, this explanation has ecological validity problem. Research on cultural learning strategies suggests that when choosing beliefs for imitation learning, people tend to consider contextual and content factors rather than the truth value of beliefs. On the other hand, due to the absence of universally accepted criterion for theory selection recognized by all scientists, the best theory choice always fails. I will develop a minimum model for the best theory choice to defend the scientific progress's cultural evolution approach. The criterion for the best theory choice is the mark of a scientific school's establishment and the demarcation line with each other. As a scientific school's member, a scientist could select the best theory as his/her learning model according to the school's criterion. Hence, it is plausible for the approach to explain scientific progress. Finally, my model will show a scientific school is a driver to improve the local scientific progress, and the competition between schools promotes global scientific progress. The school's size and the scientific reasoning diversity decide a result of the competition.

Keywords: Scienctific Progress; cultural evolution; Theory Choices; cultural learning strategies; scientific school

1. Introduction

Science is the most successful cognitive activity. From the cognitive view, why science is successful is that scientific cognition tracks the truth. However, cognition evolution could not justify scientific cognition because adaption, rather than the truth, is the force of evolution. Furthermore, many cognitive mechanisms that natural selection shapes will negatively influence standard scientific research, such as confirmation bias [1], essentialism [2], teleological thinking [3]. Although the type of cognition is irrational to scientific research, some scholars, for example, Gerd Gigerenzer, think of it as ecological rationality because it is an adaptive toolbox by which human ancestors could adapt to the corresponding ecological environment [4]. If scientific cognition is distinct from ecological cognition, we cannot gound the cognitive origin of science on natural selection. In some sense, the origin and development of science are beyond human understanding.

Recently, de Cruz and de Smedt developed a model (hereafter D & D Model) to explain the scientific progress in cultural evolution theory that scientific theories will approximate the truth without an appeal to the truth-tracking of scientific cognition, provided that it is the transmission of scientific theories that occur in science communities [5]. The number of scientists engaging with science communication will make it possible to transmit a radically counterintuitive scientific idea in a high-fidelity way and counterbalance its information distortion during transmission. Scientists' cognitive diversity will increase the chance that they infer a better idea from the previous one.

However, Vaesen and Houkes argued against D & D Model that the tractability assumption as the model's premise is not valid [6]. Scientists can not select the best theory as their imitation object because there is no generally received theory choice criterion. What is more, the tractability assumption is inconsistent with cultural learning strategies. Therefore, D & D Model is replaced by Vaesen and Houkes's agent model (hereafter V & H Model). V & H Model shows the scientist demography plays little role in truth-approximation during the whole development stage of science because cultural learning strategies are useless and biased.

If V & H Model is valid, it is limited to explain scientific accumulation in virtue of cultural evolution models. However, science is also one of the cultural phenomena, and it also instantiates cultural evolution. In this article, I propose an approach to address the inconsistency, i.e., to loosen the theory selection criterion and decrease the scientific community size. An integration of the model with my proposal will give us an insightful view to understanding scientific progress, and according to which we could make policies to facilitate scientific progress. I will develop a simple theory selection model, and it shows scientists can select the best theory, i.e., the strong tractability assumption is plausible.

The second section will outline a theory of cultural evolution and clarify the necessary conditions for cultural evolution. The third section will introduce the cultural evolution model of scientific progress. The fourth section will deal with the relationship between evolution and progress and clarify this article's understanding of scientific progress. The fifth section will propose a minimum theoretical choice model, indicating that the scientific school will reach a consensus on theory choice. Finally, this article believes that the cultural evolution model is a new way of understanding scientific progress. The described conditions for scientific progress help formulate scientific policies and promote the further development of science.

2. Cultural Evolution and its Cognitive Mechanism

There is no doubt for most people that science is progressive. However, other fields of knowledge, unlike science, are rarely recognized as having an upward trend. No one would think the sonnet is more advanced than Homer's epic, expressing human emotions better and embodying literature's essence more. No one would think traditional Chinese painting is inferior to Western modern oil paintings. George Sutton, a famous historian of science, has a similar view:

> *The saints of today are not necessarily more saintly than those of a thousand years ago; our artists are not necessarily greater than those of early Greece; they are more likely to be inferior; and of course, our men of science are not necessarily more intelligent than those of old; yet one thing is certain, their knowledge is at once more extensive and more accurate. The acquisition and systematization of positive knowledge is the only human activity which is truly cumulative and progressive.* [7, pp. 3–4]

Although many cultural phenomena have intergenerational accumulation and inheritance, progress is unique to science. Why is science progressive but other cultures not? Can scientific progress be characterized by the general model of cultural evolution?

Before answering this question, it is necessary to discuss the theory of cultural evolution briefly. Cultural evolution is a changing process of the social distribution frequency of cultural traits. The frequency of social distribution of some cultural trait will increase after social transmission, and some gradually decrease even disappears. In the 1970s, some scholars have begun to understand the intergenerational inheritance and evolution process of culture according to biological evolution and believe that culture is also a biological phenomenon of "descent with modification." [8] Cultural evolutionists think culture is not an "icing on the cake" type of cognitive achievement but an indispensable means of adaptation to enhance the chance of survival and reproduction. Because culture carries helpful information for human survival, it can make up for the over-universal biological traits formed by natural selection that are not suitable for specific natural environments.

For example, cassava is rich in starch, has a high yield, and has strong adaptability, drought tolerance, and infertility tolerance. Still, untreated fresh cassava contains cyanogenic glycosides, which cause hydrocyanic acid poisoning. Cassava was first introduced from South America to West

Africa by Portuguese colonists in the 17th century; unfortunately, its processing methods were forgotten to introduce. The result was that local people eat untreated cassava and suffered chronic cyanide poisoning(Henrich, 2016, ch.7). Native people in South America process cassava by soaking, drying, crushing, and other methods, removing most cyanogenic glycosides in it. This kind of cultural knowledge cannot be inherited from generation to generation through genetic coding and can only be spread widely in the community through social learning. In this sense, culture has adaptive value because it can help individuals quickly adapt to the natural and cultural environment, which is the secret of why human beings could be such a successful spread all over the world [9].

The accumulation and evolution of culture involve two different processes: selection of cultural traits and high-fidelity transmission . The cultural learning mechanism is the cognitive strategy that people adopt when choosing cultural traits. As a cognitive preference, the cultural learning mechanism makes different cultural traits have various possibilities to be selected and learned. Researchers have found two types of contextual biases in cultural learning mechanisms: 1. individuals choose successful individuals or individuals with high status and power as imitation objects; 2. individuals choose and learn the most frequently occurring behaviors in the group [10]. Also, people have a preference for the content of cultural traits. Certain cultural traits can attract human cognitive attention and conform to the natural cognitive processing process of humans. Therefore, they are easier to be selected and learned. Religious beliefs are more accessible to people's attention than scientific ideas because humans have specific natural cognitions for generating and processing religious concepts to understand religious beliefs naturally without deliberate learning. For example, it is easy for people to believe that a supernatural agent is the creator of the universe and rules human's elusive destiny. People often resort to him to explain their "magical" happens to themselves. It is hyperactive Agency Detection Device (HADD) that explains this people's cognition pattern. Cognitive scientists claim that this cognitive mechanism helps develop and accept religious ideas (Barrett, 2004).

The evolution of culture requires cultural traits to be spread in a high-fidelity manner. Suppose people cannot obtain a complete cultural trait from the behavior of others. In that case, the cultural trait may be distorted in communication repeatedly, and it will lose its adaptive value because of information loss. The high-fidelity transmission of cultural traits also requires specific cognitive mechanisms, including understanding others' intentions and teaching interaction between learners and demonstrators. The acquisition of cultural traits involves an understanding of the intention behind the behavior of others. Only when others are regarded as actors with the same intentions as one's own can the adaptive value of imitation be indeed emerging, and culture has the characteristics of intergenerational accumulation [12]. If learning from others is unilateral and cannot guarantee the high-fidelity transmission of complex cultural traits, mutual teaching between learners and demonstrators can help learners master the learning content more accurately. As civilization develops, more and more cognitive aids have helped human learn to get cultural traits in a high-fidelity way, such as language, writing, guilds, scientific communities, and large-scale education systems.

However, the selection mechanism of cultural traits and the high-fidelity communication mechanism are only the cognitive prerequisites for the cumulative evolution of culture. Cultural evolution is also affected by geographic environment, population size, and complexity of cultural traits. Jared Diamond mentioned the decline of Tasmania's civilization in his book, Guns, Germs, and Steel, indicating a critical role of population factors in cultural evolution [13, pp. 312–13]. Ten thousand years ago, due to rising sea levels, Tasmania was cut off from mainland Australia, and there was no cultural exchange between the residents and mainland aborigines. Although only thousands of residents living on the island have proliferated to this day, the population is too small to maintain the complex culture. Cumulative evolution ultimately remains only an elementary material culture. Some scholars have used the mathematical model of cultural evolution to show that even if community members can choose the best craftsman as imitation objects, the computer simulation demonstrates a small size of community populations cannot counterbalance the cultural information loss. Complex cultural traits will degenerate into simpler ones in the communication process and eventually die out [14].

Before entering the next section, it is necessary to mention the tractability assumption in this mathematical model. This hypothesis assumes that the learner can successfully identify and imitate the individual with the most skills [14]. This hypothesis is critical. It is the focus of the dispute between the D & D model and the V & H model and the focus of this article. Do all types of cultural evolution make the tractability assumption? Not so.

The tractability assumption is an extreme form of cultural preference, which only applies to certain cultural types. Firstly, humans do not have the natural cognitive mechanism for selecting the "best" cultural traits because we have different standards for comparing the advantages and disadvantages of cultural traits. Secondly, the absence of universal selection criteria does not mean that there are no selection criteria. For technology, the best technology may be the most efficient, or can solve the most problems or the most cost-effective; for science, the best scientific theory may be the most accurate theory, or theory with the most potent explanatory power, or the theory with the most accurate prediction. Finally, the lack of selection criteria for "best cultural traits" does not mean that culture cannot produce cumulative evolution. As long as there is a preference for cultural selection strategies, cultural evolution can occur under the condition of a large population [15]. For example, literature evolution could be viewed as an accumulating process rather than a progressive process because there are no received criteria for the best literature.

Science is one of the cultural types, but it is also the most special because scientific development is generally regarded as a directional and progressive culture. Therefore, in addition to satisfying the necessary conditions for cumulative cultural evolution, scientific evolution also needs to meet other requirements, for example, the tractability assumption. Therefore, if the population is too small to maintain complex cultural traits and cannot guarantee the cumulative evolution of culture, then enough population plus the tractability assumption, the cultural evolution model can illustrate scientific progress. Initially, erroneous and imprecise scientific beliefs can continue to progress in the scientific community's communication. The following will discuss the cultural evolution model of scientific progress and whether the tractability assumption will have a fatal impact on the model's explanation efficacy.

3. Cultural Evolution of Scientific Progress

Why does science have a progressive evolutionary process compared to other things, and what is the driving mechanism that promotes scientific progress? Many scholars naturally compare scientific progress with biological evolution when addressing this puzzle. They consider that the historical development of science and biological evolution is both a "gradual inheritance" phenomenon. Therefore, it seems that the mature biological evolution theory should provide a whole set of ideas for understanding scientific progress.

Donald Campbell proposed "Blind variation and selective retentions " to explain knowledge growth [16]. Karl Pope believed that scientists boldly achieved scientific progress by developing and falsifying scientific hypotheses. The hypothesis that can "survive" the falsification is more likely to be confirmed as accurate. The longer the "survival" time, the more the hypothesis tends to be established [17]. Stephen Toulmin's theory of "conceptual variation and intellectual selection" shows that scientific progress is the process by which the scientific community chooses the conceptual variation that can best solve scientific problems [18]. A general theory selection process developed by David Hull is applied to explain the biological evolution and the evolution of the biological taxonomy theory. Biological evolution and theory evolution results from the selection of "reproductive differences" produced by replicons and interactors in the process of interacting with the environment [19].

However, the evolution process will debunk the strategy to justify scientific progress analogous to biological evolution. As we know, it is a realistic stance to explain progress in terms of fitness because this approach supporters believe that the selected biological traits and scientific theories are all related to "true." Moreover, the evolutionary debunking argument(hereafter EBA)demonstrates that individuals' successful adaptation to the natural world does not mean that natural cognitions could track the truth. Suppose we use the evolution argument to justify scientific progress further. We have to explain that science can still be progressive in terms of some special mechanism for scientific research, despite that natural cognitions can systematically mislead scientific research. It is the cultural evolution model of scientific progress that can justify it.

The mathematical model applied to the scientific progress initially was used to explain the Tasmanian civilization's decline [14]. de Cruz and de Smedt use it to explain why and how scientific progress is possible [5]. In D & D model, the degree of truthfulness of a scientific belief or problem-solving efficiency, namely z, denotes scientific progress. The higher z-value, the higher the truthfulness of scientific beliefs or the efficiency of problem-solving. In general, scientific progress is a process, i.e., a specific scientific community selects the best scientific belief and refines it to increase its z-value. The crucial part of the mathematical model of cultural evolution is the relationship between z and the possibility of the theory being selected. The relationship could be described in the Price equation:

$$\Delta\bar{z} = \underbrace{cov(f,z)}_{\text{selective transmission}} + \underbrace{E(f,\Delta z)}_{\text{noise reasoning}} \tag{1}$$

$\Delta\bar{z}$ denotes the average change of truth-approximation of a scientific belief; $cov\,(f,z)$ denotes the correlation between f, which is the frequency of transmission of a scientific belief, and z-value. $cov\,(f,z)$ means the higher the degree of truth of a scientific belief, the higher possibility for scientists to select, learn, and transmit it. It reflects scientists' cognitive preference to choose scientific beliefs. $E(f,\Delta z)$ denotes the change degree of a scientific belief during transmission due to different scientists' understanding. The more frequent the transmission of a scientific belief, the higher the degree of variation in it.

However, equation (1) cannot give the general conditions for scientific progress. The tractability assumption is a condition under which the D & D model makes further inference. It assumes that scientists can choose the best scientific belief (or hypothesis, or theory, or model, or idea) as their learning object by appealing to cognitive values, intuition, experiments to assess the merits of different scientific beliefs [5, p. 422]. If the best scientific belief is denoted as h, and its true approximation degree is z_h, therefore, $f_h = 1$ and $f_{(\sim h)} = 0$, equation (1) can be simplified to:

$$\Delta\bar{z} = z_h - \bar{z} + \Delta z_h \tag{2}$$

Equation (2) describes the average change of truth-approximation of scientific beliefs between two successive scientists' generations. A second-generation scientist will pick up the best scientific hypothesis from the first-generation scientific community's hypothesis pool, namely, h. $\bar{z}$ denotes the average true value of all scientific beliefs about a particular phenomenon or problem in the second-generation scientific community, and $z_h - \bar{z}$ indicates the infidelity degree of h during the transmission process. Δz_h denotes the mutation rate of the best scientific hypothesis, i.e., h, after different scientists reconstruct and review it. The two together constitute the change value of the true degree of a scientific belief.

The transmission of scientific beliefs cannot be a copying process from a scientist to another. A particular scientific belief will be reconstructed due to scientists' investigation, which is influenced by their natural cognition, theoretical background, and scientific community's research programs. The Gumbel distribution in the D & D model is used to characterize the distribution of the maximum or minimum of a z-value of a scientific belief that a scientist researches further. The Gumbel distribution in the D & D model is used to characterize the distribution of the maximum or minimum of a z-value of a scientific belief via a scientist researches it further. According to the Gumbel distribution, $\Delta\bar{z}$is determined by three parameters, i.e., α represents the difficulty degree of a scientific belief in question, β how diversity of scientific reasoning on it, and N is the number of scientists engaging with the scientific transmission. Hence the evolution process of scientific beliefs can be described by the following formula:

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$$\Delta\bar{z} = -\alpha + \underbrace{\beta\big(\gamma + Ln(N)\big)}_{alway\ spositive} \tag{3}$$

According to equation (3), we could conclude that if a scientific belief would progress continually, i.e., $\Delta\bar{z}$-value is always positive, and there must be an approach to compensate for the information loss of a scientific belief resulting from the infidelity of science transmission. Furthermore, the higher α-value it is, the more difficult it for a scientist to grasp. In D & D model, α-value is indeed $z_h - \bar{z}$, which means to the extent to which scientists could ultimately identify and grasp the best scientific belief. Since h is the best theory but complex or radically counterintuitive to most scientists, they hardly identify it and hard to promote it. The best theory h would be transformed into another theory h' during its transmission, which is easy for scientists to grasp, viz., the $z_{h'}$-value is less than z_h-value. It is the reason there must be an approach to counterbalance the α's negative influence.

We can infer from equation (3) that scientific transmission makes scientific progress possible as long as the number of scientists and scientific reasoning diversity is fair enough. Many scientists investigate the same best current scientific belief, which could compensate for the lost information of a scientific belief during transmission. The number of scientists plays a role in the fidelity transmission of science. Furthermore, some luck mutation of a scientific belief will occur when scientists further examining it. An insightful scientist or a scientific community with great diversity reasonings, i.e., β-value is high, will generate a more truth-approximating scientific belief based on the current best one. The new one may be more parsimonious or have a more extensive range of explanations or more accurate predictions than the previous best one. For example, Planck, a German scientist, develops a precise blackbody radiation law to compute the relationship between energy and electromagnetic radiation from a blackbody. Rayleigh-Jeans formula and Wien's law were the best before Planck's law to calculate the relationship. However, the Rayleigh-Jeans law is in line with experimental results at large wavelengths but strongly inconsistent with results at short wavelengths, while Wien's law is the opposite. Planck uses the interpolation method to incorporate the two laws and ultimately develops his law. We can think of Planck's law as the successful mutation of the former two laws, which gives the correct radiation at all spectral ranges.

This kind of scientific progress is similar to Newton's dictum that "If I have seen a little further, it is by standing on the shoulders of Giants." Therefore, the tractability assumption is so important to make the D & D model work. However, Vaesen and Houkes think the tractability assumption invalid because although cultural learning strategies cannot help scientists choose the best scientific belief. Contextual bias and content bias are inconsistent with the tractability assumption. If scientists can adopt various methods to select the best theory among many alternative theories, as the tractability assumption holds, it is not easy to understand why the Ptolemaic system had dominated history entirely for a long time. As early as the third century BC, ancient Greek astronomer Aristarchus of Samos (ca. 310-230 b.c.) proposed a heliocentric system, but it did not develop further until Copernicus proposed the heliocentric system again in 1548. It takes almost 1800 years to replace the geocentric system with the heliocentric one. The V & H model demonstrates that the number of scientists (β-value) will not promote the truth-approximation of scientific beliefs without tractability assumption [6]. It seems not an intuitive ability for scientists to select the best scientific belief. Therefore we could not think of the tractability assumption as the valid premise of the cultural evolutionary model of scientific progress without any argument for it. To save the D & D model, I will justify why and how it is possible for the tractability assumption. The core argument is to rethink the meaning of "the best" in "the best theory" and specify what scope a scientific belief could be transmitted within. Next, I have to deal with the relationship between evolution and progress and answer whether science evolution is progress or not before to defense the tractability assumption.

4. Is Scientific Progress a Culutral Evoluton?

Cultural evolution is just a process of social distribution change of cultural traits(Mesoudi, 2011), which is unnecessary to instantiate the progress. However, science is in progress. So it is required to

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explain away the concept gulf between evolution and progress. Unfortunately, the D & D model did not complete it and failed to recognize it seriously. David Hull developed a general model of selection processes and argued for science evolution and biological evolution as two instances of the general model. Hull thought that the evolution process had no predisposition for change in a particular direction because the environment to which different organisms adapt was not comparable. Nevertheless, the object of scientific investigation is the eternal and unchangeable natural laws, and we can compare different scientific beliefs in terms of the extent of truth approximation. As Hall said, "If no such regularities exist, scientists could not approximate them." [19, p. 467].

In Hull's view, science's evolution or progress is the steady increase in its conceptual inclusive fitness. Conceptual inclusive fitness in science is the recognition that scientists receive from other scientists(Hull, 1988, p. 282). In other words, a more successful scientifical belief is more adaptable than others to the scientific community. Hull says: "Increasing one's conceptual inclusive fitness in science means increasing the number of replicates of one's contributions in the work of successive generations of other scientists."(Hull, 1988, p. 283). How does a selection mechanism warrant the best scientific belief is of the highest conceptual inclusive fitness? It is the cooperation within the scientific community and competition between different communities. Cooperation and competition are essentially strategies that individual scientists use to pursue scientific credibility. A scientist has to develop an original scientific hypothesis to gain credits through other scientists to cite it to increase their research credibility, which is cooperation. However, it is the competition that to cite another's research is to give credits to others. Scientists prefer to cite an origin, well-argued scientific hypothesis to justify their research, which means it has good conceptual inclusive fitness. Is it possible that a full-flawed hypothesis has good fitness? Impossible. Because competitors will review it as could as possible to gain credits. Even if scientists within the same community will cite it regardless of its theoretical flaws, other scientists from other communities nevertheless abandon it. Cooperation and competition make a scientific hypothesis approximate to the truth.

David Hull took an actual instance to illustrate his theory from the history of science. Phenetic taxonomy had been the mainstream of biological classification before the 1960s, according to which the fauna and flora were categorized into taxon by similar phenotypic characters. In contrast, cladistics was another biological classification in which organisms were categorized in groups based on the most recent common ancestry assumption. For example, according to phenotypic taxonomy, crocodile and tortoise belong to the same class of reptile, while according to cladistics, crocodile and birds belong to the same class. The two classification approaches had been competing for almost 40 years. Finally, cladistics wins. Hull explained why cladistics wins. First, phenetic taxonomists branched out too quickly; second, cladists refined their methods, making biologists master it easier without becoming a cladists expert(Hull, 1988, p. 519). In other words, an increasing number of scientists have cited the cladistics.

However, scientists nevertheless identify which theory is the best currently because there are usually more than two theories with empirical adequacy for the same phenomenon [21, pp. 192–3]. There are no defined theory choice criteria that scientists could apply to measure which theory is the best. Therefore, scientists would appeal to other considerations not pertaining to theory justification, such as personal preference, interest relative, authorities, and something else. If possible, we do not infer well-cited theory (or theory with high inclusive fitness) is the best one in principle. I think it is a challenging problem not only for Hull's general selection model but for all approaches to explain scientific progress in evolution.

However, is the tractability assumption tough to be justified? No. It is a philosophical illusion that there are theory evaluation criteria that are unique, sufficient unambiguous, and accepted by all scientists. If we want to justify science progress is global, the criteria are needed. But in my view, science's global progress is just an appearance resulting from we oversight the complexity and diversity of scientific theory development. The science development is in multiple tracks, rather than not single-track. The refinement of a theory is local progress; the increasing number of scientific disciplines, the increasing division of the scientific community, or the integration of disciplines or communities arising from competition and cooperation between scientific communities are also scientific progress. Some people may question whether these criteria not pertaining to theory justification could measure threaten scientific progress. I think we cannot first assume this possibility before thinking about how scientific progress is possible. We should pay more attention to whether a scientific community makes his theory local progress successful. And I will argue that the tractability assumption is valid in a small-sized scientific community, i.e., a scientific school. I have to illustrate the relationship between the local progress of science and a scientific community before justifying the tractability assumption in section five.

Local progress of science results from a scientific community promotes its theory, although we can not necessarily infer that it is the best even if it wins the competition between scientific communities. However, a scientific community without a well-established academic atmosphere and a sufficient number of members could not push forward the theory development. As the scientific community disintegration, the theory that it supports will be extinct, at last, a part of science history. However, we keep in mind another pattern of scientific competition and cooperation. If a theory was too novel to comprehend for contemporary scientists or had little chance to be cited because it was published in an unavailable journal, few scientists, if any, would cite it, promote it. Nevertheless, the theory will be re-developed possibly by future scientists, even will win in a competition with others. For example, de Vries, Correns, and Tschermak independently discovered inheritance laws in 1900, while Mendel discovered it as early 35 years as they did [22, Ch.17].

Suppose the primary form of scientific progress is the continuous improvement of scientific theories. In that case, regardless of science's global progress, the conceptual framework of biological evolution is applied to scientific progress. Hence, to deal with the problem of the best theory choice is to think about how a scientific community establishes. Competing on multiple theories is only related to whether local progress can occur. It is the basic approach to the tractability assumption I develop in this article.

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. A Solution to the Best Theory Choice

5.1. Theory Choice and Establishment of Scientific School

Since there is no specific and fixed theory choice procedure, theory choice will be easily mistaken as an arbitrary and personal decision-making behavior. If scientists apply some cultural learning strategies rather than theory evaluation criteria to select a theory as the learning object, science development will stop, even decline. The V & H model demonstrates that the number of scientists (i.e., N)and scientific reasoning diversity (i.e., β) do not maintain the science development if scientists did not select the best theory. Whether to choose the best theory is critical to promote scientific progress. I will argue that there is a dialectical relation between theory choice and local scientific progress, viz., theory choice criteria are necessary for local scientific progress, and the latter justifies the former.

Kuhn has a similar view when dealing with whether theory choice is arbitrary without theory choice criteria. Kuhn believes that theory choice depends on a mixture of objective criteria and personal factors, but it does not mean any scientist could identify the best theory arbitrarily(Kuhn, 1977). Objective criteria of theory choice are what trained scientists apply to collectively determine which theory is the best within a certain community, and personal factors include individual scientist character, ontological commitment, theory evaluation preference. Personal factors will not threaten the objectivity of theory choice because an individual scientist needs to justify his choice if his community confirms his choice. Otherwise, if he chooses a theory based on arbitrary personal factors, the scientific community will not accept it. Kuhn says:

> *But scientists may always be asked to explain their choices, to exhibit the bases for their judgments. Such judgments are eminently discussable, and the man who refuses to discuss his own cannot expect to be taken seriously… Einstein was one of the few, and his increasing isolation from the scientific*

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community in later life shows how very limited a role taste alone can play in theory choice. Bohr, unlike Einstein, did discuss the bases for his judgment, and he carried the day. [23, p. 337]

For example, Kepler believed in Neo-Platonism and was obsessed with the sacredness and perfection of circular motion. However, Kepler's personal aesthetic preference was not sufficient to show the truth of Copernicus's heliocentric model unless he did not participate in scientific community communication. Hence Kepler would promote his theory in consist with some received theory choice criteria, such as accuracy, fruitfulness, consistency, and simplicity. Scientists are hard to identify the same best theory because of multiple dimensions of theory evaluation. However, that scientists fail at making the same choice does not mean they fail at making an objective choice, and a theory choice influenced by personal factors or cultural learning strategies is not necessarily an arbitrary choice. Therefore, we need to rethink the meaning of "the best" in the best theory choice, and we need to justify it is possible to list adequate criteria for theory choice. To complete these tasks, we have to investigate a scientific community's deep structure, and we argue that the science transmission scope should be limited to specific science schools.

The cultural evolutionary model for scientific progress highlights a scientific community's role in science knowledge generation, justification, and modification. However, what is a scientific community, and by what do we individualize different scientific communities? Equation (3) demonstrates the scientific progress is determined by the number of scientific community members(i.e., N), the difficulty degree of a scientific hypothesis(i.e., α), and the diversity of scientific reasoning(i.e., β). Obviously, different scientific communities have different values of N, α, and β. In other words, these values are determined by the scope and internal structure of a corresponding scientific community. That is the reason why we have to consider the community further.

A scientific community is a group where there is some consensus on scientific matters among members. According to the degree of consensus, a scientific community could be further subdivided into a more specific community, from a general scientific community to a specific disciplinary community or a community focusing on a particular question. However, unless a specific community reaches a consensus on the best theory, it will not be qualified as a scientific community. However, it does not mean different scientific communities have the same criterion on what the best theory is. For example, accuracy, prediction, and uniformity of physics theories may be impossible for sociological theories; it is also impossible to reduce sociological theories to physics theories because they are a special science [24]. Although physicists and sociologists may both be members of a scientific community and share the most basic research norms, it is difficult to say that they have substantial scientific research exchanges. D & D model requires that the members of the scientific community must reach a consensus on what the best theory is and be able to carry out diversified reasoning about it (that is, the β-value in equation (2) is as high as possible), and the members of the community have substantive communication to meet this requirement. In this sense, only scientific schools can do this. Diana Crane believes that the common social structure of knowledge has been largely ignored, which is usually regarded as a single entity, and put forward very general norms without considering the changes in different majors and sub-specialties and different periods [25].

Crane has studied the relationship between knowledge growth and community structure and showed that a community with frequent academic exchanges could contribute to scientific knowledge's logical growth. Moreover, this kind of community is an exchange network formed by a cooperative group of scientists, also called an invisible college or school. A scientific school is a scientific community with an exact research program. The formation of schools can be understood by Kuhn's scientific paradigm theory. In Kuhn's theory, the scientific paradigm is a set of scientific research methods and fundamental commitments which scientists shared by similar education, professional training, and reading the same technical literature. The scientific school is the bearer of a specific paradigm, such as the Bourbaki School of mathematics in France.

A scientific school is like an ethnic group that must have a stable boundary. Boundaries are the fundamental cultural values shared by members. Within the boundary, ethnic group members play the same game and share consistent evaluation and judgment standards [26, pp. 9–38]. A scientific school is a uniform and homogenous group formed by individual scientists. Initially, a respectful

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scientist recruits students as his apprentices and establishes a partnership with other scientists. It is necessary for different scientists to establish an apprenticeship and partnership that reaching a consensus about research objects, research methods, and research goals. Different research consensus between scientific schools is like an unbreachable wall deliberately resisting schools' influence with each other. A scientific school will ignore the counterevidence to their theory, defend it as could as possible, and never give it up quickly. Their essential job is to narrow the distance between the current theory and the initial research goal for scientific school members.

Early research on the Skinner School in psychology indicated that the school only studied its theories, and the journal it founded did not publish other schools' theories to avoid unnecessary disputes between schools. Once a member adopts a new research method, it may lead to differentiation within the school [25]. The establishment of the new school means the formation of new theory choice criteria. According to Kuhn, within the paradigm,

> *what one must understand, however, is the manner in which a particular set of shared values interacts with the particular experiences shared by a community of specialists to ensure that most members of the group will ultimately find one set of arguments rather than another decisive [27, p. 200].*

When we specify a scientific community as a scientific school, a scientific school's establishment basis provides a rigorous justification for the tractability assumption. If the members cannot reach a consensus about the best theory and identify whether the scientific progress occurs within it, the science school may not qualify as scientific. Once a new scientist joins a particular school, he/she has to accept and use these criteria to select the best one like a naturalized has to obey the law no matter what they are. There is no choice between theories a scientist has to make, and there is no more than a set of criteria within a school. Hence, the theory choice problem will not substantially threaten the cultural evolution model of scientific beliefs. In my opinion, scientific progress is local, the process of approximating the school's research goals and defending its research agenda.

5.2. The Mini Model of Best Theory Choice

Here, a mini theory choice model is developed to demonstrate that it is possible to select the best theory to meet the scientific school's tractability assumption. Let us assume there are some scientific hypotheses for a particular aspect of the natural world, such as H1, H_2, H_3, H_4, H_5. Each hypothesis has one dimension of theoretical advantage, H_1 for simplicity, H_2 for consistency, H_3 for prediction, H_4 for accuracy, H_5 for fulfillment. According to the received theory comparability view, there is no hypothesis H_1 ~ H_5 superior to the other four. Therefore, scientists cannot select the best theory as their model, which does not meet the tractability assumption tractability assumption. However, if each theory choice criterion is used as a consensus to establish a scientific school, scientific school members can select the best theory according to the school's purpose. Under what condition can we identify a scientific theory that will be progress?

The second-generation H_i is better than the first-generation H_i, if and only if,

1. *It is better than the first-generation H_i in the dominant dimension;*
2. *It has made breakthroughs in other dimensions with retaining the dominant dimension of the first-generation H_i.*
3. *It has made breakthroughs in other dimensions with exceeding the dominant dimension of the first-generation H_i.*

For example, H_1, has a simple structure, insufficient predictive, and inconsistent with background theories. Although H_2 has a complex structure, its prediction is more accurate and consistent with the background theory. The traditional view is that H_1 and H_2 are not comparable, and it is impossible to judge which is better. We know Ptolemy's geocentric system was better than Copernicus heliocentric system in prediction accuracy but worse than in structural complexity. We think Ptolemy's and Copernicus' is the best theory in their respective schools. Moreover, if the first-generation Copernicus heliocentrism's prediction accuracy could improve, it demonstrates the theory's progress.

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After the first cultural transmission, the second-generation H_1 has improved its predictive power while maintaining a simple structure. Furthermore, it becomes the best scientific theory for the subsequent cultural transmission. After the second transmission, the third-generation H_1 has a simpler structure and accurate prediction, but it may also solve inconsistency with the background theory. If H_2 has no substantial development after cultural transmission, any rational scientist supporting H_2 should switch to learning the third generation of H_1.

Of course, even in this case, the H_2 school can still stubbornly believe that its own theory is "the best." At this time, the development of scientific theory enters a stage of competition among schools. Community-scale(i.e., N) and reasoning-diversity (i.e., β) determine which school is the winner during the school competition. According to the cultural evolution model simulation, supposing that a school fails to attract scientific newcomers or the school's academic atmosphere is gradually weakening, the school will decline into a simple one like Tasmanian society, fail to achieve partial scientific progress, and eventually dies away. However, sometimes a scientific school would be active over a long time without any scientific progress. The school has advantages not pertaining to scientific considerations, such as faculty resources, capital interests, political positions, and it could nevertheless attract new scientific newcomers to join in. Furthermore, a scientific school sometimes defends its theory and squashes its competitors in political ideology [28, pp. 579–97]. And in this case, it could still be the mainstream school in a particular research field for a while.

From the 1930s to the 1960s, Lysenkoism, based on Michurinist agrobiology, was the dominant biology school in the Union of Soviet Socialist Republics (USSR). Lysenko developed the wheat yarovization (vernalization) based on acquired genetics, but it did not achieve the expected increase in yield. Lysenko suppressed the development of genetics and evolutionary biology by seeking Joseph Stalin's support. Lysenko persecuted Biologists who believe in genetics and evolutionary biology. Lysenkoism achieved a decisive victory, especially after the August 1948 VASKhNIL Session, and it became the only correct biological theory [29]. Many geneticists and evolutionists switched to Lysenkoism to avoid persecution and sought academic benefits during this period. Nikolai Ivanovich Vavilov was a famous agronomist, botanist, and geneticist in the USSR. After his arrest, Iohann Eichfeld, his former student, took over him as the head of the (VIR, Vsesoyuznyj Institut Rastenie-vodstva). After realizing the scientific theory's political position, he gave up genetics and claimed to use Lysenko's research method. Another Vavilov's student also pretended that a rust-resistant high-yield wheat cultivar was based on Michurinist agrobiology rather than genetic methods.

However, suppose a particular school of science entirely relies on external factors and cannot make progress in its research theory, even without competitors. In that case, it will die out because of the lack of active and effective scientific communication within the community.

6. Concluding remarks

Even though natural cognitions generally possessed by humans do not track the truth as its evolutionary goal, the cultural evolution model of scientific progress shows that scientific beliefs approximate to the truth by scientific transmission. However, some scholars questioned that the tractability assumption, the model's working assumption, does not conform to the general cultural learning strategy, such as context and content biases, which will prevent scientists from choosing the best scientific belief as their learning model. If the argument is valid, then scientific community size does not play a role in scientific progress [6].

This article argues for the D & D model that the tractability assumption is the fundamental consensus that any scientific school holds. All scientists do not favor the same theory choice criteria, and they have their theory preferences, metaphysical commitments, and educational background. Even they would choose scientific beliefs that will be wrong in the future. However, the best theory choice is not a personal affair but a social affair because the choice justified will be accepted by a scientific community. It is not hard for scientists to choose the best scientific belief because any individual scientist is a specific scientific school member. The consensus on what is the best theory is the fundamental commitment to become a member of it. The consensus is also the essential requirement for establishing the scientific school and demarcation from other scientific schools. Although it is challenging to achieve global scientific progress because the best theory choice criteria between schools are incommensurable, the cultural evolution model can explain local scientific progress. In other words, the scientific school is the main force that promotes scientific progress. Whether the scientific school is of a prosperous research phenomenon or declines like the Tasmanian civilization depends on the scientific school size (i.e., N) and the scientific reasoning diversity (i.e., β).

Furthermore, once we specify a scientific community as a scientific school, the crucial factor determining scientific progress is the scientific school size and the scientific reasoning variety, rather than whether there is the best theory choice criterion. We can conclude some tips about scientific progress from the cultural evolution model. On the one hand, for the country and society, the cultural evolution model shows it is necessary to popularize science for scientific development because it needs scientific reserve forces. It is essential to attract a large number of new scientific newcomers to join a scientific school. On the other hand, academic freedom without any external force is crucial for scientific progress, especially when political interests kidnap the best theory choice criterion it would seriously threaten scientific progress.

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