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Relation between Science and Technology

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국문 요약

이 논문에서는 과학과 기술의 관계에 대해 기술은 응용 과학이라는 계층적 모델을 비판하고, 그 둘은 서로 독자적 영역을 가지면서 상호작용 한다는 상호작용 모델을 옹호한다. 상호작용은 모델에 의하면, 기술은 비록 과학으로부터 많은 지식을 빌려오지만 과학으로부터 오지않은 자신의 지식영역이 있다. 기술을 구성하는 여러 성분 중에서 특히 공학과학으로서의 기술에 중점을 두었고, 공학과학의 핵심을 설계에 있다는 것을 이야기 하고 공학설계의 특성에 관해 논의했다. 기술적 지식이 과학적 지식과 다른 것 중 하나는 기술적 지식의 변화 모델이 과학적 지식의 변화 모델과는 다르다는 것이다. 기술적 지식의 두 가지 중요한 모델인 쿤 방식의 모델과 변이-선택 모델을 논의하면서 두 모델의 약점을 이야기 했다. 과학과 기술의 상호과학적 지식의 작용은 '매개된 상호작용'이라는 모델을 제시했고 그 모델의 가능성에 대해 간단히 이야기 했다. 산업계의 연구는 과학과 기술 사이의 상호작용의 한 형태이다. 이 산업계의 연구를 통해서 과학-기술은 점점 구조화되고 자율성을 띈다. 과학자와 공학자는 인격적 주체자이기 보다는 단순히 산업연구 구조의 한 부분이 되어 버린다.

Abstract

In this paper, I advocate interactive model which treats science and technology as distinguishable subcultures each with their own bodies of lore and competence against the traditonal hierachical model which treats technology as applied science. For engineering science which is a component in technology as knowledge, I count design as the core part of engineering and discuss the characteristic of engineering design. I also critically assess the models of technological knowledge change, Khunian model and variation-selection model to understand the relation between science and technology. I propose a model that science and technology interaction is mediated interaction. I only outline the plausibility of this model. Industrial research is a modern form of the interaction between science and technology. I discuss Reich who focused on the broad background of industrial research and MeyerThurow who has microperspective in industrial research. The conclusion I draw from the discussion, is that through industiral research, the science-technology interaction become more structured and autonomous, and the scientists and engineers become simply patrs of the structure of industrial research rather than the personal subject.

Science-technology relationship has been a long standing topic in history of technology. Staudenmaier tells that no theme, in society of history of technology's early years seemed as well as focused as important, or as interesting as the relationship between science and technology.[1] Otto Mayr searches for various form of interactions of science and technology through history and concludes that inductive approach shows practically no sharp criterion between science and technology. He also argues that to find sharp critera between science and technology by logico-deductive become failure. Based upon these results, he concludes that "to analyze such past discussions of the science-technology relationship and interpret them against their historical backgrounds would be a rewarding task for the historian." "It might make us conscious of how deeply our own views of the science-technology relationship as well as of its historical interpretations are determined by unreflected ideology." Otto Mayr's proposal sheds significant light on the character of the complexity of science-technology relationship. These Otto Mayr's results urge us to give up the hope of finding general model for the science-technology relationship. But it does not mean that direct investigation of science-technology relationship is meaningless. In my view, although we cannot find some universal principle of science-technology relationship a priori or a posteriori, through contextual approach we can find certain forms of science-technology relationship contextually. Further the study of science-technology relationship sheds some light on understanding technology as its own body of knowledge, value, and institution. Especially, since science and technology are partially seperate communities with seperate culture, it is legitimate to enquire into the form of science-technology relationship between the two cultures. And this study gives us fruitful illumination to understanding science and technology.

There are two kinds of models for the study of science-technology relationship in broad sense. One is the traditonal hierachical model which treats technology as applied science. The other model is

1) J. Staudenmaier (1989), p. 83

interactive model which treats science and technology as distinguishable subcultures each with their own bodies of lore and competence. On this model technology has its own body of knowledge which is not from science, although technology uses a lot of knowledge from science.

In this paper, I deal with science-technology relationship advocating interactive model. this paper is composed of four parts. In the first part the hierachical model, especially the concept technology as applied science is discussed: what it is to understand technology as applied science and on what basis, technology is claimed as applied science in terms of analytic and empirical method. In second part, the criticism against the hierachical model is discussed. In the third part, technology as engineering science will be discussed. In the fourth part, the models of technological knowledge change which have been proposed by various authors will be reviewed and assessed. Finally various forms of interaction between science and technology will be discussed.

1. Technology as Applied Science

In this section, what sense technology is applied science and what is the basis to claim technology as applied science will be discussed. Technology as appied science has the following meanings. Scienctific knowledge is the only source and sufficient for all technological knowledge: there is no technology without understanding underlyng science, i.e. science is necessary for technology. It is denied that technology makes any contribution to science. In this view, the thought component on technology is denied and it is claimed that technology is only practice. So the knowledge-generating by technological research is overlooked. Huxley well expressed the idea of applied science in this sense: "technology is nothing but the application of pure science to particular class of problems." Huxeley's interepretation of the phrase "applied science" has long history and has enjoyed a long life as well in Europe and the United states.

On what basis does this applied science view have been claimed ?

There are some versions of the defense for this view. I think arguments for applied science view of technology is based not upon historically proven arguments but on the misunderstanding of science. For example, Babbage followed the Baconian faith that the arts and manufacturers of the country are intimately connected with the progress of the severer sciences" As part of his campaign to reform English science in the 1830s, Babbage argued for more state support of abstract science because of its commercial utility.[2] According to Don Ihde, the applied science view is due to the following interpretation of history of modern science and technology.

"After a long dark period in European history, a revival of the Greek scientific sprit emerges within and animates what we call the Renaissance. Europeans regain an interest in nature, speculate about nature

2) Kline (1990) p. 18

and evolve a method of understanding nature which we call Modern Science. Historically this movement becomes dramatic and fulfilled in such figures as Galileo, Kepler, Copernicus and eventually becomes fully systematized with Newton." [3)]

The other argument for applied science view is based upon too narrow understanding of technology. For example, in their monumental History of Technology, Charles Singer, E.J. Holmyard, and A.R. Hall define technology as "how things are commonly done or made" and "what things are done or made."

In this phrasing, technology as "systematic knowledge of the industrial arts automatically loses its meaning and denies thought component to technology.[4)] In this view, modern technology which is clearly sophisticated and complicated arts is taken as at best applied science and is denied as independent area which produces technological knowedge.

From the analytical view point, there is a defense for applied science view. Mario Bunge is the champion for applied science view of technology. Bunge argues that four genera of rules cover the rules necessary for all human lives, and one is rules of science and technology the rules of science and technology are those norms that summarize the special techniques of research in pure and applied science." [5)] Mario bunge distinguishes pure science from applied science. Pure science deals with objective patterns or laws of nature. Applied science deals with the studies of rules prescribing the course of optimal practical action. For him technology is applied science which is the application of the theories and methods of science to practical action. So technological knowledge is scientific knowledge applied to practical action. He also distinguishes modern technology from prescientific arts and crafts. The rules of modern technology are grounded rule of applied science. We say, rules are grounded when based upon scientific laws which explain or account for their effectiveness. Arts and crafts without an underlying science are not grounded rules. According to Bunge, there are two kinds of technological theories. Substantive technological theories are essentially applications to nearly real situation of scientific theories: thus a theory of flight is essentially an application of fluid dynamics. Operative technology theories on the other hand, are from the start concerned with the operation of man and man-machine complexes in nearly real situations. Substantive technological theories are always preceeded by scientific theories. Each provides a different kind of science basis for the rules of human action.

In sum, technology as applied science can be summarized into the view which does not attribute cognitive character, i.e. knowledge and thought component to technology independent of science as a knowledge

3) Don Ihde (1984) Existence and Technics p.27
4) Edwin Layton (1974) p. 31
5) M. Bunge (1972) p. 68

source. Historians and philosopher have criticized this view. Next section, the critiques against technology as applied science will be discussed.

2. Critiques against Technology as Applied Science

For the last 20 years, historians have argued against hierachical applied science model of technology in favor of a more interactive model that views technology as an area of research and portrays the physical science as only one source of technological knowledge.[6] This technological knowledge may be called engineering science. Many historians of technology have studied the developement of engineering sciences, in the areas of hydraulics, strength of materials, aeronautics, thermodynamics and electrical engineering. Although this engineering science imports knowledge from pure science, it is autonomous body of knowledge created through the discipline of engineering. In this section, the hierachical model, the view of technology as applied science can be effectively criticized from three fronts. First critique is from historical case studies of engineering science. Second is from analytic approach. Third comes from the model of technological change. Finally, the linguistics of the terms applied science will be discussed to remove the confusion of the usage of the term applied science in various cases.

Ronald Kline[7] has shown excellent description of one of the historical cases of engineering science. It is from Steinmetz's case from history of electrical engineering. Charles Steinmetz had performed research on magnetic hysterisis in the iron cores of electric machines at a small electrical manufacturer in the early 1890s. But physicists later argued that Steinmetz equation was an engineering approximation not a physical law.[8] The knowledge which Steinmetz developed on magnetic hysterisis (in the iron cores of electric machine) is not direct application of pure physics or not the derivation from pure physics. It is engineering knowledge developed by Steinmetz himself. But Steinmetz defends his work as applied science. What Steinmetz means by applied science is not that his work is direct application but that his work is the products from scientific method, i.e. systematic, logical, inductive and deductive methods like scientific method. Steinmetz established a home laboratory then consulting Engineering department staffs with researches trained in engineering, not physics and chemistry. Steinmetz focused on theories of electric machines and natural aspects of the artificial. At GE practicing engineers applied technological theories of the type developed in Steinmetz laboratory rather than they applied pure" physics. In history of induction motor, the role of science was substantial. But the thoery based on Maxwellian electrophysics had to be modified so extensively to make it useful that one prominent engineer, Michel Pupin questioned its validity on the ground that it

6) R. Kline (1992a) p. 1
7) R. Kline (1992), pp. 127-161
8) R. Kline (1992a) p. 7

was no longer applied science. For example, the theory's mathematical structure came from Maxwell. But Maxwell's differential equations were droped and translated into forms more useful for design work: graphical analysis and complex algebras.[9]

The engineering community transformed scientific and technological information about the induction motor into a systematic body of knowledge (engineering theory or science) that could be successfully used to design these motors. The theory's derivation from experiment and mathematics, its cummulative nature, general applicability, and so forth also demonstrate its qualities as an engineering science.[10]

Edwin Layton[11] argued that although American technology went through a scientific revolution in the 19th century, the significance of scientific revolution in technology has been obscured by a commonly accepted model of the relationships between science and technology, i.e. hierachical applied science model. So he showed how the engineering community developed as mirror-image twin of scientific community in 19th century America. These engineering sciences gave technology equivalent to the theoretical and experimental departments of physical science.[12] In the hierachical model of science - technology relationship, the transfer of information is nearly one direction, the technology influence of its information into science has been recognized at best in the form of instrumentation. But the rise of engineering science such as the theory of elasticity and hydrodynamics did have an influence on science. Layton showed several examples.[13]

In analytic view point, the hierachical model has been also criticized by Layton. Without attributing thought component to technology, it's impossible to make substantial critique against hierachical applied science model. So Layton struggled to attribute the thought component to technology.[14] According to Layton, the linking of technology with knowledge, is very old far from constituting a modern, artificial formation. Aristotle defined art as identical with a state of capacity to make (there is neither any art that is) involving a true course of reasoning since architecture is an art and is essentially a reasoned state of capacity to make. Knowlege is the presupposion and product of reasoning. And technique means detailed procedure and skill and their application. But complex procedures can only come into being through knowledge.[15] So we should not take out knowledge component from technology a priori. Layton argued quoting Koyre that technology is a system of thought, an independent system different from science. Koyre considered technology a system of

9) ibid
10) ibid p. 312
11) E. Layton (1971) pp. 562- 580
12) ibid p. 576
13) ibid p. 578
14) E. Layton (1974) pp. 31-41
15) Edwin Layton (1974) p. 33

thinking based on common sense and this technical thought of common sense does not depend on scientific thought. Of course, Koyre believed that science did influence technology.[16] But the influences were not necessarily from direct result of science - its laws and findings - rather indirect influences. For example, the idea of a world governed by precise mathematical laws was transmitted to technology through Galileo's and Huygen's conversion of mechnical clock into an instrument of precision. The idea that the universe is governed by precise mathematical laws, it should be noted, was not a scientific result, but one of its presuppositions and some parts of these presupposions are from technological development.[17]

One may object to the view that such technological knowledge is so crude that we don't need to explore the technological knowledge and regard technology as autonomous body of knowledge. Therefore the knowledge character in technology has not been investigated. It is wrong. The reason why we have rarely explored the cognitive character is not due to the crude and naive character of technological knowledge. The technological character has been tacit in important part since ancient time and we have not had analytical tools to investigate the tacit knowledge.[18] So it is due to our own problolem. Recently philosophy of science developes various analytic tools to see scientific knowledge change. And scientific knowledge also has in part tacit character. Some historians and philosophers try to apply the models of scientific knowledge change to technological knowledge change. Mario Bunge is one of the advocates for applied science view of technology from analytic approach which is shown in section I. Bunge's analysis may be plausible as an account of normal technological practice. And the historical cases which are object to applied science view may be re-interpreted in favor of applied science view of technology. But in order for Bunge's formulation of technology as applid science to be true, it should explain the technological knowledge change. Gutting indicated this point well. According to him, normal technology, we may agree, is applied science. But for the case of technological revolution, especially in case of revolution in evaluation poicy itself, discussed by Wojick, the view of technology as applied science is not generally adequate. It will be adequate to the limited extent that evaluation policy is a function of theoretical scientific commitments. But other aspects of evaluation policy do not result from the application of scientific theories and methods.[19]

There are some linguistic confusions over the meaning of applied science. Thoses who argue that technological work is not just applied science in content, support that technological work is applied science. In this sense, applied science means that it uses systematic and inductive methods even though the work does not just the

16) ibid p.36
17) ibid pp.35-36
18) R.Laudan (1984), pp. 1-26
19) G. Gutting (1984) p. 59

application science. As Kline[20] examines this point very well. According to him, one of the reason why the model of applied science has had long life is that all the social groups he examined benefitted from endorsing the model. But the confusion in this sense is not important stumbling rock and can be resolved easily. The other way of linguistic confusion is related with the topic science-technology relationship itself. Otto Mayr indicates that the concepts of science and technology themselves have been changing over history. Therefore he argues that we cannot find general formular of science-technological relationship and we can find it from our own vantage point. So he argues that we have to turn to analysis of the past discussions of science-technological relationship. I do not agree to this skeptic argument. Following his argument strictly, we cannot find any model of scientific knowledge change because the concept of science has been changing over history. So we have to turn to the analysis of past discussions of scientific knowledge change, is this argument right ? I think it's obviously wrong. Even if the concepts of science and technology changes over history, there is some continuity of refereces of science and technology. So we can find contextually some kind of general model of science-technology relationship. And with the theme, science-technology relationship, we can explore various topics of history of technology and science. For example, looking at history of industrial research in view of science-technology relationships, social and cultural change in view science-technology relationship, etc..

One may ask the significance of treating technology as thought. Layton gives excellent account of that question. Layton[21] argues that an emphasis on knowledge puts the stress on ideas of men. This emphasis on knowledge further serves to direct attention to innovations in technology as against technician and this leads on the one hand toward an intellectual history of technology, on the other hand innovation suggests consideration of the role of technology in social change. Layton does not assume that "technological thought" is a single monolithic whole or that it can be uniquely characterized in any single formula.

In sum : By technological research, the knowledge of technology is generated; Although technological knowledge is compatible with scientific knowledge, science is not necessary for technology. Technology also makes contribution to scientific knowledge. The interaction between technology and science is two-way interaction and the forms of interaction are diverse. To support interactive model of science-technology relationship instead of hierachical model, it is essential to put thought or knowledge component on technology. Of course it is also important to show that technological communities and cultures is independent of scientific communities and cultures to support interactive model. But the key element is

20) Kline (1992a) p. 17
21) E. Layton (1974)

the cognitive character of technology which differenciates from hierachical model. Paradoxically a concern for knowledge serves to emphasize the importance of social history for history of technology.[22]

3. Technology as Engineering Science

In section II, what I try to show is that technology has its own knowledge component through criticizing applied science view of technology. I did' nt show what technological knowledge look like or what is the difference between technolgy and science. Staudenmaier[23] argues that there are four characteristics for technological knowledge, scientific concept, problematic data, engineering knowledge and technical skill, non of which stands alone as a complete description of technological knowledge.

In this section, one component of technology, technology as engineering science will be discussed. What we today call as engineering is not just modern products. It has its origin in the work of the master builder, the chief of works," who appeared in the valley of the Nile and in Mesopotamia with the dawn of civilization, at least by 3,000 B.C.[24] Modern engineering is one special case in history of technology. Engineering science aspect of technology is only one feature of modern technology.

3-1. General characteristics of engineering knowledge

What is the special feature of engineering science or knowledge compared with scientific knowledge or other component of technology ? Of course, there is not clear cut demarcation just as we can' t demarcate clearly scientific knowledge from other knowledge. Because the boundary between scientiific knowledge and others is blurred. As there are various kinds of knowledge in science, there are various kinds of engineering science or engineering knowledge. Yet engineering science does have characteristics which differentiate it from science. I claim that engineering science has its own ontology instead of fundmental scientific ontology.

The aim of engineering science is to produce practical and instrumenal knowledge to produce artefacts while that of science is to produce theoretical knowledge to understand nature. So engineering science often differs from basic science in important particulars.

Instead of pursuing the fundamental ontology as science does to understand nature, engineering sciences is often satisfied with just an approximate and instrumental ontology on practical rather than metaphysical ground. The character of this instrumental and approximate ontology is often macroscopic or/and fits our intuition of everyday experience. But this instrumental and approximate ontology never be reduced to the fundamental ontology of science. Engineering science has its own theoretical space built on its own ontology. For example, in solid mechanics,

22) ibid p. 41
23) J. Staudenmaier (1989), p. 103
24) James Kip Finch, (1961) p. 319

engineers deal with stresses in continuous media rather than a microcosm of atoms and forces.[25] The continuous media is macroscopic and well fits our intuition of everyday experience of material. And the solid mechanics cannot be reduced to atomic physics. Engineering theory and experiment came to differ from those of physics because it was concerned with man-made devices rather than directly with nature. Thus, engineering theory often deal with idealization of machines, beams, heat engines, or similar devices in its own way. Of course, there is some exception. In a certain cases, the essential concepts and essential ontologies in engineering science can be reduced to the fundamental concepts and ontologies in science. Kline already indicated this point criticizing Layton.[26] In electrical engineering, especially in circuit theory, current and voltage are essential ontologies. They are not macroscopic, and they can be reduced to the properties of atoms and electrons. But the engineering theory built upon these concepts in science is much different from scientifiv theory. For example, even though the essential ontologies(voltage and current) and fundamental concepts of circuit theory (resistance, inductance and capacitance) can be reduced to those of science, the circuit theory built on this concepts is much different from scientific theory. When one may try to translate whole circuit theory into physics, one find the reduction need so complicated transactions that the reduction is nearly impossible. Even though the reduction is successfully achieved, the reduced scientific theory is no more scientific theory because it lacks explanatory power which is the virtue of scientific theory due to the complexity of the reduced theory. That' s the reason why circuit theory use its own ontology instead of more fundamental ontology of science although it can be reduced to fundamental ontology of science.

3-2. The anatomy of engineering design

The other important characteristic feature of engineering science is design. According to Layton, design is the characteristic feature of Engineering which is assumed to comprise all technology. Of course, the features of design of all the engineering sciences are not the same. Only contextually we can find the fruitful model of the structure of engineering design. In this section, the anatomy of Engineering design knowledge will be discussed based on Vicenti' s developement on history of aeronautics.

Vincenti[27] describes the anatomy of Engineering design knowledge as follow: First how engineering problems get posed for devices and system, second, the categories of design knowledge, third, knowledge-generating activities. Finally Vincenti touches the persnal and social agents who cut across and embody the knowledge-generating activities. Here, first and second parts are mainly discussed.

25) E.Jr. Layton,(1976) p.695
26) R. Kline (1987) p. 312
27) W. Vincenti (1990) chapter 7. pp. 200-240

The following problem sources for technology have been proposed by Laudan.[28) 1) Functional failure of current technology, 2) Extrapolation from past technological successes, 3) Imbalances between related technology at given period, 4) Potential rather than actual technological failures.

These sources depend upon social and economic contexts. For example, the functional failure of current technology includes not only physical failure(for example, the bridge is broken) but also the failure according to the standards of the community of technology practitioners. The standards for perception of failure may be different even within the same technology according to practitioners' group nurtured by different social and economic factors. Vincenti argues that Laudan's four sources depend upon social economic factors more than internal factors of technology. So Vincenti proposed additional four problem sources which depend upon internal factors more than external factors of technology : 5) perception of new technological possibility, 6) Internal logic of technology, 7) Internal needs of design, 8) Need for decreased uncertainty. distinguishes social standards. These proposed four sources provide problems within technology. According to him, 5) depends upon both internal and external factors of technology. It is hard to make the general distinction between internal and external factors of technology because the internal factors depend upon external factors. Strong program in sociology of science does not want to distinguish external social factor from internal factor of science. They believe that the very content of knowledge in science can be socially construced. I think Vincenti does not like this view. So he proposed additional four problem sources which heavily depend upon internal factors of technology. I also agree with Vincenti because to find out internal factors contributing to technology change can help explain the success and reliability of technology.

The categories of engineering knowledge proposed by Vincenti[29) are as follows : 1) Fundamental design concepts, 2) Criteria and specifications, 3) Theoretical tools, 4) Quantitative data, 5) Practical consideration, 6) Design instrumentalities. Of course, these categories are not entirely exclusive. Some items of knowledge can embody the characteristics of more than one category. The relationship of these categories is hierachical. Designers setting out on any normal design(Vincenti), bring with them fundamental concepts about device in question. The forms of existence of these concepts are both explicit and implicit form. They may exist implicitly in the back of the designer's mind. Fundamental design concepts are composed of two components, operational principle and normal configuration. Operational principle provides the criterion by which success or failure is judged in the purely technical sense. Vincenti argues that the operational principle provides an important point of difference between science and technology.[30)

28) R. Laudan (1984) pp. 85-86
29) W. Vincenti (1990) p. 208
30) ibid p. 209

Because operational principle originates outside the body of scientific knowledge and comes into being to some innately technological purpose, it is very important in technology but not in science.

By normal configuration, Vincenti means the general shape and arrangement that are commonly agreed to best embody the operational principle. Shared operational and normal configuration define the normal technology(or design) of a device(in the sense used by Constant.[31] The design criteria and specifications are built upon the fundamental concepts.[32] With the design criteria and specification, engineers carry out their design function. In order to do this, they use a wide range of theoretical tools, i.e., mathematical method and engineering theory. When we analogy the engineering knowledge to broad spectrum according to the order of abstractness or mathematical involvement, at one end of the spectrum, the knowledge is directly related with producing artifacts and at the other end of the spectrum is more abstract and mathematically oriented empty of empirical knowledge about artifacts. The circuit theory in engineering develops the topological network theory to deal with very complicated networks(VLSI). The topological network theories are uniquely engineering knowledge are no physics can develop such a theory. Within these theoretical tools, engineers assesses quantitative data and these theoretical tools should be constructed to be able to deal with quantitiative data for the physical properties of the artifacts. These quantitative data can be divided into two kinds. One belongs to descriptive knowledge of how the devices and process will perform under given assumption and allow the calculation of the data. The other belongs to prescriptive knowledge which includes the safety factors and regulation factors imposed by goverment agency, and engineering standards. The industries have diverse prescriptive data. Therefore, the theoretical tools should be developed to be able to fit the required prescriptive data and assess the descriptive data. theoretical tools and quantitative data are, by definition, precise and codifiable; they come mostly from deliberate research. But in order to produce artefacts, practical consideration should be counted. This practical consideration distinguishes engineering science from science. Besides the analytical tools, quantitative data and practical considerations, Vincenti includes "design instrumentalities," as a part of anatomy of engineering knowledge. The reason is that the "knowing how" and procedural knowledge have concentrated mostly on the generation of new theoretical and quantitative knowledge used in the design process. The design instrumentality gives engineers the poser, not only effect designs where the form of the solution is clear at the outset, but also to seek solutions where some element of novelty is required.

The categories discussed above are not static. Engineering knowledge is highly dynamic and is changed over time. In

31)E. Constant (1980) pp. 1-32
32) W. Vincenti (1990) p. 213

different historical periods, different categories are emphasized. For example, three hundred years ago, theoretical tools obviously played a far lesser role compared with other categories than they do now. Here we find that technology has its own body of practical and theoretical knowledge with mathmatically structured knowledge. So modern engineering is worth called engineering science. Ancient engineering can be also called engineering science in view of the level ancient science.

4. The models of growth of Technological Knowledge

Once technology is regarded as having its own body of knowledge, we may ask what is the model of technological knowledge growth, or how technological knowledge changes. But as R. Laudam indicates, we have sparsity of useful analytic tools for understanding change and development within technology itself.[33] Historians and philosophers try to apply the model of scientific knowledge change to technological knowledge change. These attempts are to view technological knowledge as a paralell structure to science. This view has been recently developing. R. Laudan excellently describes the three barriers which impede to treat technology as knowledge. The first barrier is that technological knowledge is quintessentially tacit, second one is the attitude to identify technological knowledge with applied science. The third one is the very richness and variety of approaches to the study of technology. For example, the study of the wide spread cultural and social effects of technology reveals little about the cognitive content of technology. R. Laudan argues that it is appropriate to analogies and disanalogies between scientific knowledge and changing technological knowledge and apply the models of scientific knowledge change to technological knowledge change, justifying the removal of the three barriers.[34]

One may ask what kind of knowledge should constitute the basis for understanding technological change ? Following Laudan, an informed knowledge of the history of technology constitutes an important basis instead of sociological and economic knowledge of contemporary technology. Since sociological economic analysis put priority on sociological and economic change, not technological change, it is hard to find internal dynamics of technological theory based upon economic and sociological knowledge of technological change.

In this section, I discuss two kinds of approach proposed for understanding change and development within technology in cognitive view point. One approach is the application of recent work of philosophy of science about scientific knowlege change to technology change. Here, the application of Kuhnian model will be dealted. The other approach is the application of Campbell's variation-selection model to technological knowledge change. This approach is developed by Vincenti.[35]

33) R. Laudan (1984) p. 1
34) R. Laudan (1984a), Introduction" pp 1-26
35) W. Vincenti(1990)

4-1. Application of Kuhnian model to technology change

Edward Constant applied Kuhnian model to the technology change and investigated the turbojet revolution.[36] According to Kuhn's conception of science, the cognitive locus of science is a well defined by community of practitioners. Likewise Constant finds technological knowledge to comprise tradition of practice which are properties of communites of technological practitioners.[37] Like Thomas Kuhn's normal science as puzzle-solving", he proposed the concept of normal technology which technological communities usually practice. This normal technology comprises the improvement of the accepted tradition, or its application under new or more stringent conditions". And the techonological community embraces a wide variety of groups concerned in different ways with techonolgy. For example, the aeronautical community writ large is composed, at the least, of manufacturers, of civil and military users, of governmental and community agencies(airport authorities, for instance), and of industry, governmant, private nonprofit, and univeristy-related aeronatical sciences organizations. Manufactures, in turn, comprise communities of practitioners specializing, usually, in airframes, power plants, or accessory systems(...). Other highly specialized suppliers and subcontractors provide manufacturing organizations. Thus, the aeronautical community is composed of a multilevel hierachy of subcommunities."[38] This normal technology can be challenged from two difference sources. The difficulties through the challenge which normal techonology can not solve in normal practice are called anomalies. The first source is called functional failure, the failure of a technological system developed by normal practice to operate properly under new conditions or to meet needs imposed by technological disequilibrium of either the intersystem variety or intrasystem variety. Anomoalies of this sort arise from the activities of the technological community itself or from those of related technological communities. The second source is called presumptive anomaly' which occurs in technology not when the conventional system fails in any absolute or objective sense, but when assumptions derived from science indicate either that under some future conditions the conventional system will fail (or function badly) or that a radically different system will do a much better job. No functional failure exists; an anomaly is presumed to exist; hence it is called presumptive anomaly.[39] This presumptive anomaly would seem to represent one direct causal link between theoretical science and techonological knowledge. Constant defines technological revolution as the professional committment

36) E. Constant (1980).
Constant says that he applied Kuhn, Campbell, Popper and other scholars of science and technology but in my view, the dominant influence is from Kuhn.

37) E. Constant (1980) p. 8

38) E. Constant (1980) p. 9

39) ibid p. 15

of either a newly emerging or redefined community to a new technolgocial tradition.

According to Kuhn, revloution is the rejection of one paradigm in favor of another and , in consequence, the abandonment of one system of normal scientific practice for another. Constant's techonological revolution, by contrast, need not(and typically do not) represent an either/ or choice for the technological community. For example, the turbojet revolution did not mean the abandonment of piston-aircraft technology. Therefore, the abandonment of the old technology is not an essential feature of technological revolution. The technological communities have the standards for evaluating technological system. According to these standards, the functional failure or success is judged. Constant regards these standard as fixed. An anomaly occurs when a system does not function accoridng to these fixed standards, or when we have scientific reason to think it will not so function in the future. But in either case it is assumed that we have fixed standards for evaluating how well a technological system is functioning.[40] In contrast with the fixed standards, Wojick[41] argues that the evaluation standards themselves can be changed by some outside influences. Due to such altered standards, the anomaly can occur which was not anomaly according to former standards. David Wojick shows this point well. Wojick's central concept is the standards of evaluation policy. Such a policy comprises all of the considerations that enter into a technological community's assessment of the suitability and correctness of solutions to technological problems.[42] Thus evaluation change can be a good cause of technological revolution.

In sum, the model of the technology change pararells to scientific knowledge change follows the scheme: normal technology as problem-solving within techonological community —› Anomaly —› Technological revolution —› Normal technology.

Is this application of Kuhnian model of science change to technology change relevant ? Following Gutting,[43] Kuhn's central features of science change are 1) the interpretation of paradigm as exemplars; 2) community consensus as the ultimate basis of cognitive authority; 3) the cognitive autonomy of the community. Here, the meanings of paradigm and exemplar are different. Exemplars are universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners. Paradigm is a successful piece of science that serves a community as a model for future work.[44]

But Wojick and Constant did'nt accept Kuhn's paradigm as examplar. The acceptance of exemplar could contribute a lot to our understanding of technology. One

40) G. Gutting (1984) p. 53
41) D. Wojick (1973), pp. 238-261
42) G. Gutting (1984) pp. 53-54
43) ibid 49
44) ibid

instance is technological practices, crafts and arts, which exist independent of theoretical science.[45] In contrast to the common view that such practices are entirely unscientific and are not given knowlege component, the analysis in terms of exemplar shows that the artisan or craftsman know how to provide their model problems and solutions to a community of practitioners like scientists. I think Constant's and Wojick's view is valid only to modern technology. Here, the problem does not lie in the application of Kuhn's model to technology change but in the Constant's and Wojick's misinterpretation of Kuhn's paradigm. The second feature of Kuhn's model does not enjoy its success in technological community. In science community the standards of consensus are incommensurable with those other community(with different paradigm). I think because of this incommensurability, the science community can enjoy cognitive autority. But in technology, there is community consensus about a new paradigm, but this consensus need not replace the consensus generated by the old paradigm. It may be located in a new technological community that merely takes its place along side the old one. For Wojick, consensus about evaluation policies may fail to arise from within the technological community but may be imposed from outside. Therefore community consensus cannot enjoy ultimate cognitive authority. In both cases, the differences in scientific and technological consensus derive from the differents ways how the standards(or values) of science and of technoloy are related to the standards(or values) of the wider community.[46] The third feature of the cognitive autonomy in science community, technology community enjoys only in part. Technological community makes judgements about technological system on the basis of a fixed evaluation policy in an autonomous community. But as Constant has shown in his valuable discussion of presumptive anomaly, such judgements can be decisively affected by information from pure' scientific communities not included in the technological community. And Wojick also shows the evaluation policy of technological system can be changed due to the policy change outside technological community.[47] Therefore technology enjoys the community autonomy only in part.

Based upon these results, the application of the anti-realist Kuhnian model to technology change needs some modification. In my view, the weak points of this approach are as follows. First This approach makes light of technology's autonomous power to affect the community itself. The technological community has the standards to judge the plausibility of the development of technology but technology can create new order in the community which the community never expect. This new order affect to establish new standards according to which the success or failure of technology is judged. Second, modern technology is very

45) G. Gutting (1984) p. 56
46) ibid
47) D. Wojick (1973) pp.238-261

dynamic and the life time is very short. So the mechanism of establishing the standard is very dynamic and complex. Without mentioning this, technological change cannot be explained completely. The application of Kuhnian model to technological change is too schematic to understand technology change in detail. Third, technological community does not have ultimate cognitive character and enjoys the autonomy of community only in part. Therefore community character and its relation to other fields should be investigated more deeply compared with understanding science change case. Finally it's hard to explain the instrumental success and reliability of technology with application of this Kuhnian model. Technological success results in the credibility of science. Do the standards or consensus of the community explains these ?

4-2. Variation selection model for the growth of technological knowledge.[48]

The blind-variation and selective-retention model put forth by Donald Campbell can be applied to understanding the technological knowldege change. In this section, Vincenti's application of Campbell model will be discussed.Campbell's model contain three essential elements: (a) mechanisms for introducing variation (b) consistent selection process and (c) mechanismms for preserving and/or propagating the selected variations.[49] The discussion here will concentrate on the mechanisms of variation and the processes of selection because the methods of preservation and propagation of engineering knowledge(journals, handboolks, textbooks, engineering-schollo teaching, desgin traditions , word of mouth and so forth) are obvious in our cases. For Campbell, any variation that leads to truly new knowledge must be blind. Here, blind does not mean random" or unpremediated" or unconstrained," it is in the sense of going beyond the limits of foresights or prescience."[50] It simply denotes, in accord with Campbell's characterization, that the outcome of the variation cannot be foreseen or predicted insofar as the matter in question is concerned - if it could, the knowledge obtained would not be new. Blindeness is, however, in far from absolute. As also stated by Popper, "To degree that past knowledge enters,... blindness is only relative: it begins where the past knowledge ends."

For much of normal design, the degree of blindness involved in the generation of new knowledge may well be small because the tradition of technology community reveals the direction of technology change. The important idea is that when the outcome is not completely forseeable, the variation must in some degree be blind. To arrive at these variations, however, the designers must have gone through some kind of mental preselction process to winnow. Normal design needs detailed knowledge of the kinds categorized in former section 3.

48) W. Vincenti (1990) chapter 8 is summarized.
49) W. Vincenti (1990), p. 242
50) ibid

How to accquire this detailed knowledge? This detailed knowledge has been also acquired from a subsidiary variation selection process of some sort(subsidiary from the point of view of design, that is). So the overall scheme, then is one of a nested hierachy of blind-variation-and-selective retention processes in which the knowledge produces at one level is used in the process at the next outer level. The notion of nested hierachy is an essential feature of Campbell's model, though he employs it in a different context. For normal design, the growth of engineering knowledge can be explained by this variation-selectionprocess. But as engineering knowlege is accumulated due to the continous variation-selection processes, the nature of how those processes are carried out can be changed. For example, long-term methodological shift occurs. This long-term methodological shift complicates the attempt to generalize about the process. Vincenti describes the character of the shift itself as follows : "At all levels of hierachy, growth of knowledge acts to increase the complexity and power of the variation-selection process by (1) modifying the mechanism for variation with resulting effects on degree of blindness and size of the field of overt variation(that is, the number of variations from which visible selection is made); (2) expanding the processes of selection by trying out overt variations vicariously through analysis and experiment in place of direct trial in the environment. Modification of these mechanisms of variation as knowledge cumulates in a technology take place in several ways. First, the body of experience about what has and has not worked in the past increases, making a priori judgements easier. Second, experience within an established technology will for a time enhance the ability to conceive of novel features that have a chance of working; ultimately, however, the degree of novelty that is possible tends to be exhausted(in the absence of some radical input from outside, in which case the technology is superseded, in effect, by a new technology). Third, expanded processes of vicarious overt trial(to be detailed later) enlarge the framework within which engineers conceive what is likely to work."[51] Does this modification of mechanisms of variation explain short term methodological shift? How about when there is some radical input into technlogy due to unexpected situations ? Vincenti may argue that because expanded process of vicarious trial enlarge the frame work, new methodology can appear from this enlarged frame work. But this process is only long term process. With regard to overt variation, experiential enhancement of the ability to conceive of novel features tends, for a while at least, to widen the field of overt variation; a priori discard on the basis of experience and more accurate feeling for what is likely to work both act to narrow it.[52]

Let's see the process of selection, the second element in the variation-selection model, all entail overt trial of one kind or another. As stated earlier, growth of

51) ibid pp. 246-247
52) ibid p. 247

knowledge in a technology characteristically acts to expand the power of vicarious in place of direct trial. Such expansion is achieved by two means: (1) Substitution of partial experiments or complete simulation tests for proof test or everyday use. Such vicarious trial is especially visible in aeronautics in the widespread dependence on wind tunnels.

(2) Conduct of analytical tests" in place of actual physical trials. This too constitutes a form of vicarious trial. These two means invove the development of increasingly sophicated experimental and analytic tequniques which are also products of variation-selection process in the nested hierachy. One of the peculiar feature of selection in modern technology in comparison with ancient technology is vicarious trial form instead of direct trial. Of course in the end all designs and design knowledge must prove out in operation.

Modern technology really enjoys its instrumental success and instrumental reliability. I think this evolutionary model can easily explain the instrumental success and reliability of modern technology better than Kuhn's model because in this model modern technology is the result of survival through all the direct and indirect test during evoluted process. But this model has some weak point. With the blind-variation selection model, how is the technological revolution explained? And when enviornmental input to technology is radical, how to assess this radical input through this model ? Do we need some kind of gestalt switch? So this model is good for normal technology(or design) but inadequate for explain radical change of technology(design).

5. The Forms of Science - Technology Interactions

Price said, "science and technology move in linked but independent ways, related like a pair of dancers.... what keeps them linked is that both dance to the music of instrumentalities."[53] I think this expresses the character of the sciencetechnology relationship very well. The dance has not been always led by one partner, science through history. There have been various forms of the sciencetechnology interaction in history.

I propose that the science-technology interaction is a mediated interaction. From this viewpoint, to understand the science-technology interaction is to understand the structure and dynamics of the medium and mediated process. The medium which connects science with technology has various forms, according to the context which is changeable over time and space. The medium may be nearly a simple path which simply transfers scientific knowledge to technology for simple applications. In this view, technology as applied science means the medium is a simple path for transferring scientific knowledge into technology. The medium may also be a complex structure.

When science and technology get into this medium, new knowledge, scientific knowledge, or technological knowledge is

53) D. Price, 1984, 113.

developed. This new knowledge also has various forms. The medium may be constructed by the social group for specific goals as an external institution, or the medium may be in an individual's brain. The university and research institute are also good examples of the medium which combines science and technology.

Industrial research is another good example. Through industrial research, science can be turned into a productive force or combined with technology to participate in production.[54] In this section, the sciencetechnology interaction in industrial research will be discussed, focusing on Reich's[55] and Myer-Thurow's[56] paper. Reich shows how industrial research was founded through the investigation of the background of 19th-century America. Reich examines science and technology, and evaluates their interaction to understand the process that led to the establishment of industrial research. Industrial research is a form of scientific and technological interaction.

In order to establish industrial research, science and technology should reach a certain level. In 19th-century America, there were tremendous strides in science, both in its ability to explain natural phenomena and in the development of its educational and organizational base. Newly sophisticated commercial technologies were developed. These technologies required inventors and engineers to include components of scientific research in their technical work.

Breaking the traditon that American engineering practice had been rarely involved in research, universities offered engineering studies on the graduate level and started graduate research training. This graduate research training in fields that encompassed both science and engineering produced researchers who found their fullest application in the industrial research environment. Engineers used experimental and theoretical methods in order to generate the sorts of scientific knowledge needed by technology.

Principles and methods of science helped in testing the composition of materials, a task vital to the improvement of products and rationalization of industrial processes. This positive -though limited-experience with science was an important reason for American industry's decision to establish ongoing research programs.

The strong Enlightenment philosophy then prevalent in America saw progress coming from rational procedures of the type associated with science.

Progressivism encouraged scientists to see their use of science for industrial purposes as contributing to the advancement of society. Thus, as the 20th-century began, a growing number of highly trained scientists were willing to consider working in American industry. Therefore, industry offered a good place for science and technology to interact with each other. Industrial research became the place where extensive interactions of science and technology occurred.

54) G. Myer-Thurow, 1982, 368
55) L. Reich, 1985,12-41.
56) G. MyerThurow, 1982, 363-381.

According to Reich, the motives of American industry to continue industrial research are as follows: 1) Competition with other entrepreneurs because the new discoveries were from industrial research. 2) Industrial research made more research imperative. 3)Consideration of the industrial research process itself will later reveal how commercial and organizational factors influenced the development of this new type of American research institution.

Reich shows that science, technology, socioeconomic factors and the philosophical background were synthesized to launch industrial research. He also discussed "technological theories" produced in the Bell laboratory.

Industrial research is a modern form of interaction between science and technology. Through a case study of German manufacture, Bayer, MeyerThurow focused on how industrial research took its place in industry and its effects, in contrast with Reich who focused on the broad background of the industrial research establishment. MeyerThurow' s pespective is a microperspective in contrast with Reich's macro. The process of sciencetechnology interaction in industry undergoes through industrial research conducted in the laboratory of industry.

The interaction process is not simple. It is not just putting science into industry through building a laboratory. It is very complex process. MeyerThurow calls this process "Industrialization of invention." Before this process, in 18th- and 19th-century Germany, most technology could be modified and advanced by individuals with little trained in science or concerning with scientific principles, and producing industrially useful knowledge was not yet a main point of chemists' job in chemistry manufacture. As research expands through the creation of new research laboratories, the further division of the laboratory and elaboration of refined managerial techniques are adopted.

Thus, apart from the " external differentiation" of research from production and the respective technical laboratory, an "internal differentiation" of research came about, which led to the creation of a complex research infrastructure. The training laboratory was also established. Industrial research becomes increasingly autonomous, and innovations are increasingly reduced to the routine. The process of this interaction is composed of research and management. Therefore this process becomes a bureauocratic structure within manufacture.

Individual research is superseded by structured scientific mass work. In this structure, new jobs emerge, and we call these the industrial researcher and the research manager. This industrial research synthesizes political, economic, and social factors with technological and scientific factors. Inventive activity therefore, turns into more and more routinized structural process characterized by specialization and cooperation.

Through industrial research, the science-technology interaction becomes more autonomous and structured which ends the high rate of personal turnover. Thus, industrial research becomes structured and the individual scientist, engineer and technician become simple parts of the structured process. As Reich points out, research makes research more imperative for the industry to survive against the competition. The industrial research becomes the music of instrumentalities for the dancing of science and technology in the modern age.

6. conclusion

In this paper, I criticized the traditonal hierachical model which treats technology as applied science and advocated interactive model which treats science and technology as distinguishable subcultures each with their own bodies of lore and competence. According to the interactive model, technology has its own body of knowledge which is not from science, although technology uses a lot of knowledge from science. Once technology is views as knowledge, we need the characteristic of technological knowledge. Although there are various components in technology as knowledge, I focused on one component, technology as engineering science. In engineering science, I emphasized on design as the core part of engineering and discussed the characteristic of engineering design. I also discussed the models of technological knowledge change, Khunian model which is popular to explain progress of scientific knowledge, and variation-selection model which a kind of evolutionary model for technology change. In Khunian model it is presupposed that the model of the technology change pararells to scientific knowledge change follows the scheme: normal technology as problem-solving within techonological community ──〉 Anomaly ──〉 Technological revolution ──〉 Normal technology. What I found is that the Khunian model has weak points to understand the character of technology change. The model cannot explain the success of technology and the technological community cannot be the ultimate authority to evaluate technology as science community. I critically discussed the other model variation-selection model which is evolutionary model.

This evolutionary model can easily explain the instrumental success and reliability of modern technology better than Kuhn's model because in this model modern technology is the result of survival through all the direct and indirect test during evoluted process. But this model cannot explain the technological revolution. And when enviornmental input to technology is radical, it is hard to assess this radical input through this model. We may need some kind of gestalt switch. So this model is good for normal technology(or design) but inadequate for explain radical change of technology(design).

I proposed a model that science and technology interaction is mediated interaction. I only discussed the plausibility of this model. Industrial research is a modern form of the interaction between science and technology. I discussed Reich who focused on the broad background of industrial research and MeyerThurow who has microperspective in industrial research. From the discussion, I conclude that through industiral research, the science-technology interaction become more structured and autonomous. The scientists and engineers become simply patrs of the structure of industrial research rather than the personal subject. Next project is to develop the idea of mediated interaction for science-technology interaction more deeply through the application to the industrial research institute and university-industry cooperation.

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