Yet Another Paradigm Shift?: From Minds-on to Hearts-on

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ABSTRACT

Since science was first taught in schools, maybe during the 18th century, school science education has experienced many substantial changes in its goals and nature over the period. The historical changes are usually referred to by some key terms, like, mechanics' institutes, object lessons, heuristics, general science, inquiry, STS, misconceptions. To characterize these changes, science educators frequently use some slogan-like analogies, referring to parts of the human body to indicate the movement of science education during a particular period of time: for example, 'Hands-On' for inquiry movement during 1960s-70s, 'Minds-On' for constructivist movement during 1980s-90s. In this paper, we briefly summarize the overall historical development of science education in Britain, then further expand the analogies to cover the overall process, that is, Ears-On → Eyes-On → Hands-On → Minds-On. To illustrate future directions of the 21st century, we propose a new analogy, 'Hearts-On', and also discuss the meanings and implications of a 'Hearts-On' analogy by illustrating how this new paradigm can be applied to reflect various current trends of science education, particularly in Korea. In addition, a parallel historical change between school science and science museums & centres is discussed.

Key words: Hearts-on, Minds-on, Hands-on, Eyes-on, Ears-on, paradigm of science education, science museum

I. Introduction

In 1963, following upon a first conference in Paris in 1960, a Conference on Physics in General Education was held to discuss the problems of the teaching of physics as part of the general education of all children in Rio de Janeiro, under the auspices of the International Union of Pure and Applied Physics(IUPAP). In his address, Professor S. C. Brown of the MIT, then a president of ICPE(International Commission on Physics Education), pointed out the lack of interactions between scientists and the general public:

> This tremendous and rapid growth of science has resulted in a phenomenal involvement of our culture with science, but there has not been a corresponding acceptance of science as part of our culture. As physicists we are all aware of this. We are constantly confronted with evidence that the

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> world at large looks on our field as one reserved for the narrow, mathematically endowed specialist, contributing only to our technological surroundings, talking a special language of his own, occasionally nowadays honored for his intellectual achievements that, hwever, the public makes no effort to understanding. (Brown, 1964, p.13)

Brown criticised the traditional way of teaching physics in schools: "I believe that the reason for the public's image of science in general and physics in particular derives from the attitude of our schools. ... We have been teaching physics in the framework of laws to be learned, of formulae to be brought out and applied to solve problems, and of routine laboratory exercises aimed at arriving at predetermined answers."(Brown, 1964, p.14).

At the beginning of the 1980s, Fensham(1981) suggested a new sort of school science, what he called 'hand science', emphasizing the mastery of practical skills based on scientific knowledge. He contrasted this approach, named 'Tom Sawyer' approach, with the previous approaches, 'head science' of the 1960s - represented by *PSSC* and *Chem Study* of the USA, *Nuffield* of the UK - and 'heart science' of the 1970s - represented by *Nuffield Secondary Science* of the UK and A.S.E.P. of Australia. In contrast to his new 'Tom Sawyer' approach, he called these approaches, in turn, 'Wonderland' and 'Disneyland' approaches.

> "Head science" with its emphasis on big ideas and the structure of knowledge; "heart science" with its more random, pleasure oriented approach without real rigour or structure, have both failed in their turn to have significant impact on the majority of students. The intentions have been good and noble - so what can we do in the 1980's to achieve the scientific literacy we desire? (Fensham, 1981, p.53)

In his analogy, Fensham categorized post World War II time into three periods, i.e. the 1960s, the 1970s, and then the coming 1980s. He characterized the 1960s as a period of learning conceptual structures of science, requiring students' cognitive efforts. On the other hand, he saw the 1970s as a period of delivering students the pleasure of learning science, thus more emphasizing emotional aspects than cognitive ones. From the above analogy, it seems that he considered that learning science needs both sides of learning science, cognitive as well as affective, and that the best way to achieve this is through the mastery of practical skills based on scientific knowledge. For this reason, Fensham argued that the new kind of learning for the coming 1980s needed to be the learning of 'hand science'.

Apart from whether or not Fensham's characterization of the development of science education is the most appropriate to describe the historical process, it is always informative and useful to reflect on the past and to try to draw a new picture for the future of science education.

In this article, we will suggest a new framework with a different set of analogies to reflect the historical development of school science. The proposed framework consists of several analogies which, in turn, relate the parts of the human body to the features of school science education of a certain period of time. In addition, we will propose a new paradigm of science education, named here 'Hearts-On', for the new 21st century, and explain some key features of the new paradigm with examples. The parallel historical change in science museums and centres is also briefly summarized.

Ⅱ. A Brief History of School Science: From Ears-on to Minds-on

Here, we will briefly summarize the historical changes of school science education during the last two hundred years, particularly in Britain, which has shown the most typical development processes during the period.

For centuries, education in England was the responsibility of the Church of England, and it was not until the end of the Victorian period that the clerical monopoly of schools and universities ended. It is for this reason that so much of English scientific activity took place within an essentially religious context. Scientific instruction consisted, in the main, of Aristotelianism, imbedded in the curriculum of 'the seven liberal arts' (Brock, 1990).

The increase of various technological activities at the beginning of the 19th century stimulated a demand for workers who were knowledgeable about how newly developed machinery works and how to best operate the machinery, based on relevant scientific principles. One of the responses to this need was the establishment of Mechanics Institutes for the working class in major cities and towns throughout the country (Hudson, 1851 Cardwell, 1972). Lectures were given on the principles of areas of science such as Mechanics, Heat, Light, and Chemistry. Practical work in classrooms and lecture halls consisted of lecturers demonstrating the facts of science in front of the audience (Nott, 1997). In addition to class teaching, lecture, and demonstration, the Mechanics Institutes also usually held exhibitions in which many educational items as well as new development from the industry were displayed. After the vast expansion between the 1820s and the 1840s, however, the movement of Mechanics' Institutes had faded away since the 1850s, and its original aim to teach scientific principles was replaced by more broad and liberal ones to teach nearly all subjects, including social activities (Turner, 1927; Bishop, 1994).

Science was a late starter among school subjects, as it was in the university. The teaching of science in elementary schools began to get under way in the 1840s, through the influence of remarkable men such as Richard Dawes, J. S. Henslow and Henry Mosleley (Layton, 1973). However, the progress was quickly checked in 1862 through the introduction of a system of Payment by Result. Although this system was modified about ten years later to take some account of science, the situation of science teaching in training college and elementary schools were far from satisfactory (Ingle & Jennings, 1981).

During the late 19th century, particularly compared with other major subjects, Elementary Science, together with Object Lessons, was the fastest expanding Class Subject, specially compared with other more traditional subjects, such as English, Geography, Needlework. During the second half, in general, there had been a steady growth of all major branches of science - i.e. Mechanics, Botany, Chemistry and Magnetism and Electricity, while there had been a dramatic decrease of Latin subject (Jenkins & Swinnerton, 1998).

Science teaching during the second half of the nineteenth century can be characterized particularly with the Object Lessons. The Object Lessons has its origin in the view of some educators, such as J. A. Comenius and Heinrich Pestalozzi, that children learn through their senses and should be led from the known to the unknown. The method was considered particularly suitable for teaching science, and consisted of bringing into the classroom either natural or man-made objects, each of which would form the basis of a lesson. This approach was introduced in Britain during the first half of the nineteenth century and further popularized during the second half of the century (Turner, 1927; Chung, 1994; May, 1998).

In 1878 the London School Board issued a syllabus of Object Lessons for the younger pupils and of elementary science for the optional subjects and the more specialized subjects for the examinations of the DSA(Department of Science and Arts). In 1889, T. Twining, an enthusiastic teacher who played an important roles for vitalizing elementary science especially by introducing 'peripatetic science demonstrations' until the introduction of Armstrong's heuristic method, provided a Suggestive Scheme for science teaching in elementary schools. His scheme basically consisted of two parts: the first part of simple Object Lessons covering Standards I to III, and the other part of the basic knowledge of natural sciences covering Standard Ⅳ and above - the Standard corresponds to today's grades. According to the Code of 1895, the Object Lessons became compulsory in Standards I to III of elementary schools. This led to a considerable increase in the number of children taking Elementary Science as a Class Subject in the upper standards (Turner, 1927).

As the main value of Object Teaching, the following three principal uses were emphasized: (ⅰ) to teach the children to observe, compare, and contrast; (ⅱ) to impart information and (ⅲ) to reinforce the other two by making the results of them the basis for instruction in Language, Drawing, Number, Modelling, and other Handwork. Among the above uses, the first use was considered to be the most important. Some other educational advantages were also recognized, such as, to encouraging children to contact directly with nature, and to develop a love of nature and an interest in living things. While the educational principles of the Object Lessons were sound enough, in practice, the Object Lessons frequently degenerated into boring rote learning. Together with the Object Lessons, the second half of the century was, in large part, the period of the establishment of science as one of the core elements of the school curriculum, by emphasizing the aspect of pure science as a means for mental training.

In the last decades of the 19th century, there grew up a body of opinion on the value of science teaching and particularly of laboratory instruction in schools. The main figures of advocating the importance of school practical work were the famous scientists, such as T. H. Huxley, C. Maxwell (Song & Cho, 2001). In particular, Professor H. E. Armstrong, who was a guiding spirit of the British Association Committee which placed a great emphasis on laboratory activities, advocated a system of teaching in which the pupil should discover things for himself. This was known as the heuristic method, and soon was considered to be the most desirable way to be pursued in school science (Turner, 1927; Jenkins, 1979). The heuristic method intended to place students as far as possible in the attitude of the discoverer. It was believed that through this approach students would learn more effectively than if they were given the solution didactically because the student-investigators are genuinely interested and involved in finding a solution to a problem (Brock, 1996, XIX, p.5).

According to H. E. Armstrong, however, the provision of sophisticated laboratories and their equipment alone could not be the solution for practical work in school science. He emphasized the importance of using everyday things rather than ready-made apparatus, and workshops rather than laboratories.

> Commence experimental studies at the very earliest possible moment, so that children from the outset may learn to acquire knowledge by their own efforts, so that observing and experimenting become habits.

> As to appliances, there is a very wrong idea that very special and expensive accommodation must be provided. This is not the case. There must, however, be space in which the work can be done; there must be a workshop, and much should be done with home-made apparatus. Use ordinary articles, medicine bottles, jam pots, saucepans ...; invaluable opportunities are lost by providing everything ready made. (quoted in Nightingale, 1962)

At the very beginning of the new century (i.e. January 1901), the Science Master's Association(SMA)-at first APSSM, now ASE-came into being. The year 1902 is also considered to be the beginnings of important steps towards a unified system of education in England. The Education Act of 1902 co-ordinated all forms of education under local education authorities and this swept away the old ad hoc system which had been inherited from the days of *laissez faire* (Argles, 1964).

Despite the popularity of Armstrong's heuristic method, after the turn of the century, triggered by the experience of World War I, the growing appreciation of the impact of science upon society and of the necessity of the teaching of science for a wider audience gave a great impact towards two new main movements, i.e. *General Science* (Fawns, 1998) and *Science and Citizenship* (Jenkins, 1979). The later illustrates a typical example of the STS movement in school science during the first half of the 20th century, particularly driven by the socialistic ideas towards the relation between science and society (Song, 2001).

A growing realization that the British education system needed to be changed in order to provide school science teaching to a wider audience with more emphasis on the relevance, industrial and humanistic aspects of science, was echoed by a lecture series called 'Science and Citizenship' which lasted for almost twenty years from 1938 and which was reported in the *School Science Review*, then the only nationwide professional journal for science educators, and by a group of professional scientists who had socialist ideas toward society. Lancelot Hogben was one of the key member of the group (Werskey, 1978) and delivered the second lecture of 'Science and Citizenship', titled "Biological Instruction and education for Citizenship" (Hogben, 1942). Hogben's main idea, illustrated in this lecture as well as in his famous and million-seller science textbooks, *Science for the Citizen* (Hogben, 1938), was that science education should be a way of teaching citizens for promoting democratic society and to achieve that science need to be taught in more integrated, utilitarian and humanistic manners, for example by showing the usefulness, relevance, historical and democratic aspects of science (Hogben & Hogben, 1998; Song, 1999 & 2001).

The 1960s and 1970s were the period of innovation of science education led by the USA and soon spread across the world. In Prof. Glenn T. Seaborg's, the director of CHEM Study, forward to *The CHEM Study Story*, which contains a complete chronicle of the development of the project, the main purposes of the project were clearly outlined.

> The general objectives of the Study were to develop new teaching materials for the high school chemistry course, including a textbook, laboratory experiments, and films. The more specific objectives were to diminish the then current separation between scientists and teachers in the understanding of science, to stimulate and prepare those high school students whose purpose was to continue the study of chemistry in college as a profession, to encourage teachers to undertake further study of chemistry courses geared to keep pace with advancing scientific frontiers, and

> thereby improve their teaching methods, and to further even in those students who would not continue the study of chemistry after high school an understanding of the importance of science in current and future human affairs. It was decided from the first to have the course be strongly based on laboratory experiments and be applicable to all students who take high school chemistry (Merrill & Ridgway, 1969, vi).

Like the USA, the UK witnessed the development of numerous academically-oriented programs, such as *Nuffield* projects, during the 1950-60s. However, during the 1970s, there had been growing criticism against the discipline-centered science education and some new noticeable approaches had been made to compensate the contemporary trend. For example, although its main focus was on the integrated approach in school science, the *SCISP* was quite successful to illustrate the importance of the relationship between science and society. Following this example, *Science in Society* and *SISCON-in-Schools* were more ambitious in developing genuine STS programs. These two projects were developed simultaneously and took the form of modules, rather than of textbooks. Nevertheless, *Science in Society* was more concerned with the applied and industrial aspects of science, while *SISCON-in-Schools* was more inclined to the historical, philosophical and social aspects of science (Song, 2000).

During the 1980s, far more ambitious attempts had been made to develop full-scale STS programs, i.e. *Salters' Chemistry/Science* and *SATIS*. These two programs were developed with the active corporation from the ASE and soon became the typical examples of the STS approach across the world. Besides the similarities between them, *Salters'* approach is more application-oriented, subject-oriented, and textbook-like while SATIS is more socially-oriented, issue-oriented and module-style (Song, 2000).

Since the 1980s, together with the STS movement, there has been a vast expansion of research on students' conceptions based on constructivism across the world. Britain was not an exception. The most important effort in the UK was the start of CLISP(Children's Learning in Science Project) led by Prof. R. Driver at Leeds University, and this project triggered a number of similar studies not only in Britain but also in many different countries. This constructivist approach soon became the main paradigm of science education, and became known as 'Minds-On', in contrast with 'Hands-On' of the 1960s and 1970s, which particularly emphasized the processes of scientific inquiry activities. It is true that the idea of the 'Minds-On' paradigm is still the main driving force of current research activities across the world.

The following shows a brief summary of British science education.

until 18c	focused on reading the classics of natural philosophy from the past
1800	the 1st mechanics' institute, Anderson's Institute, established at Glasgow
1840s	pioneering science teaching by Richard Dawes & John S. Henslow
1851	opening of the Great Exhibition, London
1853	establishment of the Department of Science and Arts
1862	the Education Department's Revised Code
1871	introducing 'Payment by Results' (science as a specific subject)
1878	introducing 'Object Lessons' in elementary curriculum
1901	the firstscience teachers' association, APSSM, established
1903	H. E. Armstrong's *The Teaching of Scientific Method* published

1938	L. Hogben's *Science for the Citizen* published
1963	ASE(Asso. for Sci. Educ.) established
1960s	Nuffield physics / chemistry / biology projects
1970s	*Science in Society* & *SISCON-in-Schools* projects
1980s	*SATIS* & *Salter's* Projects
1988	introducing *Science in the National Curriculum*
1998	*Science beyond 2000* published

So far, we have briefly reviewed the historical development of science education particularly in Britain. The history of science education can be analyzed from many different viewpoints. Although it is very difficult to divide the past into a series of periods of distinctive features, it would be useful to do so because such time division could give us a grand picture through which we can review the history and forecast the future of science education. What we propose here is to categorize the overall period into four main periods: until the 18th century, from the beginning of the 19th century to the middle of the 20th century, 1960s and 1970s, and from 1980s until the end of the 20th century.

This categorization of the history of science education is basically based on some important historical changes or events, particularly in the UK's experience: for example, the start of the mechanics' institute movement in 1801, the beginning of the professional association for science education, APSSM(the Association of Public School Science Masters) in 1901, science curriculum innovation movements during the 1960s, such as *Nuffield, Nuffield Secondary Science*, the emerge of research on students' misconception, based on constructivism in the 1980s.

In order to characterize and compare the periods of the historical development, we propose to consider six aspects, as shown in Table 1: period of science as..., background philosophy, essence of science learning, focus of science teaching, examples, and corresponding analogy.

It is true that the above characterization inevitably contains a considerable degree of over-simplification of the historical development. For example, the second period (19C - mid 20C), could be divided further into four sub-periods as follows: (a) the beginning of 19C - mid 19C :

Table 1. The Changes of Science Education Paradigm

Aspect \ Period	until 18C	19C-mid 20C	1960-70s	1980-90s
Period of science as	natural philosophy	school subject(s)	discovery method	personal constructivism
Background philosophy	deductivism	empiricism	positivism	constructivism
Essence of science learning	logic & reasoning	knowledge & utility	concept structure & discovery process	prior experience & cognitive conflict
Focusing of science teaching	philosophical argument	demonstration of usefulness	scientific inquiry process	children's thinking process
Examples	*Principia*, *Dialogue*	mechanics' institutes, object lesson	*Nuffield* programs, Alphabet programs	CLISP etc.
Corresponding analogy	**Ears-on**	**Eyes-On**	**Hands-On**	**Minds-On**

the period of mechanics' institute movement; (b) mid 19C - 1880s : the period of school subject and of object lesson; (c) 1890s - 1920s : the period of Armstrong's heuristic method; (d) 1930s - 1950s : the period of *General Science* and *Science and Citizenship* movement. Nevertheless, we believe that despite some minor changes in the general long-term trend, the period can be summarized as 'Eyes-On' as shown in Table 1, especially compared with the 1960s & 1970s. Thus it would be still meaningful, for science educators maybe not for the historians of science, to characterize the historical periods according to some important events in the history.

Ⅲ. A New Paradigm: 'Hearts-on' Science Education

So far we have reviewed with some degree of oversimplification the overall historical change of science education by using human body analogies, referring to the parts of the human body. And the overall pattern of the historical development of the paradigms could be summarized as follows: Ears-On → Eyes-On → Hands-On → Minds-On.

Then what would be the next paradigm of science education for the beginning of the 21st century? The answer we propose here is 'Hearts-On' science education. The reasons why science education needs to be Hearts-On can be summarized as follows:

• Through the last two centuries, science education has secured its position as one of the major school subjects. Students, parents and the general public agree with the idea that science is essential for education, not only for the personal development of individual students, but also for the development of society and nation as a whole. However, since there is still a big gap between school science and public culture, science is usually practised only in the context of schooling and examination. In many societies, science is alienated by a majority of students and by the general public. People are only interested in the fruit of the development of science and technology, but do not want to participate in the tough work of learning science. Unless science succeeds to show itself as an essential part of the general culture of man, science would be isolated from the public and by most students, and continue to be reserved only for the narrow specialists.

• In general, we, science teachers, have emphasized only cognitive and practical aspects of learning science. Sometimes we have tried, with limited success, to motivate students to study science by showing how scientific activities can be joyful. Particularly, during the last two decades, researcher of science education have heavily focussed on securing sound understanding of scientific concepts based on so-called constructivist philosophy. However, as we are all well aware, science has become much too important to modern life. Society can not exist at all without science and requires a great deal of responsible management of science and technology. It is always important to consider science together with humanism, not only focussing on the welfare of human beings, but also emphasizing the harmonious interactions between man and nature. Science should serve for human development, but science without humanism could result in catastrophe for the world. In this sense, we believe that the general philosophical background of science education should be 'scientific humanism', although there should be further discussions on what this really means.

• In oder to teach science as a culture and to teach it on the basis of scientific humanism, the essence of science learning needs to be not only cognitive (e.g. awaring, understanding), but also emotional (e.g. enjoying, feeling), and behavioural (e.g. experiencing, participating). To achieve that, we need to emphasize students' appropriate actions as well as scientific knowledge and responsible appreciation of the relationship between science and society.

• To achieve 'Hearts-On' science, it is necessary to pay more attention to the contexts of science and science learning. Until the end of the 1980s when APU Science had been put into practice, the focus of science education usually was either on the content (e.g. conceptual structures, students' conceptions) or on the process (e.g. discovery, inquiry) dimensions, or sometimes on the combination of the both. But a number of studies in the field of science education and of cognitive psychology have shown that the context dimension plays very important roles in various areas of science learning and cognition, such as, deductive reasoning, probabilistic judgement, controlling variables, inquiry skills, memory, consistency of misconceptions, selecting cognitive strategies, problem solving, interest, attitudes, and so on (e.g. Song, 1997). It became now a general agreement that the context of science education is at least as important as the content or the process dimensions (e.g. Gunstone, 2001).

Table 2 illustrates some features of 'Hearts-On' science education discussed above.

Table 2. Features of the New paradigm, Hearts-On science Education

Aspect \ Period	21C
Period of science as	culture
Background philosophy	scientific humanism
Essence of science learning	cognitive, emotional and behavioural
Focusing of science teaching	the context of science and science learning
Examples	context-rich approaches, scientific field trips
Corresponding analogy	**Hearts-On**

The main features of 'Hearts-On' science education can be illustrated by the following goals which are hoped to be achieved by students :

- to understand the core of science,
- to enjoy the joy of science,
- to feel the beauty of science,
- to experience the usefulness of science,
- to become aware of the responsibility of science,
- to participate in the development of science.

The most important elements of Hearts-On science education would be how to consider and put into use the context dimension. Kwon(2000) illustrated the extended meanings of the context dimension by comparing it with 'text'. (see Table 3) Although we try hard to teach students the text of science, what they learn is the context in which the text is embedded. If we are not

Table 3. Text vs. Context

if TEXT is...	the CONTEXT is....
- smell	- aroma
- trees	- forest
- words that teachers say	- message that students hear
- contents in textbooks	- meanings and values of the contents
- Newton's laws	- Newton's life & ideas and relations to Galileo's & Einstein's theories

successful in teaching science, it would not be due to the text which has been little changed for the last 50 years, but rather due to the context coming with the text.

If so, how can we deliver the appropriate contexts while we teach the text of science? One of the answer to this question would be the STS approach to science teaching. But what we have learnt from the experience of implementing the STS approach for the last ten years or so in Korea and some other countries is that the STS approach could not be directly applicable to ordinary classrooms due to many practical difficulties. For example, as long as we apply the STS approach, it is always difficult to avoid the problem of loosing coherent conceptual structures of science, as we experienced with so-called life-centered approaches of the 1930s-50s. In addition, adopting the STS approach in science causes the issue of reshaping the whole school curriculum because the STS approach needs much humanistic and sociological consideration, and this requires the reduction of the time allotment for science subjects, which has been already marginalized due to over-crowded school curriculum.

Table 4. Classification of the context in COPHY(COntextual PHYsics)

1. Contexts of Physics	
- Theory & concepts	(e.g. ideal conditions, thought experiments)
- Practical works	(e.g. project works, demonstrations)
- Physics studies	(e.g. history, philosophy)
2. Contexts of Natural Phenomena	
- Natural geography	(e.g. geology, astronomy)
- Natural disasters	(e.g. flood, drought, earthquake)
- Earth environment	(e.g. climate, pollution)
3. Contexts of Engineering & Technology	
- Electric appliances	(e.g. TV, microwave oven)
- Hygiene & medicine	(e.g. X-ray, ultra-sound)
- Vehicles & traffic	(e.g. ABS, tires, road signs)
- Architecture & construction	(e.g. safety of buildings, bridges)
4. Contexts of Society & Culture	
- Sports & hobbies	(e.g. tennis, ski, photo)
- Traditional cultures	(e.g. tools, cultural assets, proverbs)
- Media & cinema	(e.g. Sci-fi movies, DVD)
- Toys & theme parks	(e.g. space tops, bungee jumping)
- Arts & popular cultures	(e.g. painting, detective stories, fairy tales)

For these reasons, a group of physics educators in Korea are trying to develop a new context-rich physics teaching materials, named COPHY(COntextual PHYsics), which adopts an extensive contextual approach but does strongly maintain the conceptual structures of the discipline. Table 4 shows one of the framework of the classification of the context dimension for developing the COPHY.

Another movement currently underway in Korea, which could be regarded as an example of Hearts-On science education, is to teach physics as a culture. Recently there have been a number of attempts in Korea, specially led by Prof. S. J. Pak at Seoul National University, to develop physics/science teaching materials which are to be used for scientific field trips to various traditional and modern cultural sites, including old fortresses, temples, museums, relics, and newly built 2002 Korea-Japan World Cup Stadiums in Korea. Teaching physics as a culture also requires a wide and diverse consideration on why and how to teach physics. Table 5 illustrates from how many different aspects we can look at physics as culture.

Table 5. Aspects of teaching 'Physics as Culture'

1. As a Discipline
   - What would be the features of physics, distinguished from chemistry or biology?
   - Why do we teach physics, its aims and values?
   - How do we teach physics, as a discipline of natural science?
2. As Educational Activities
   - What would be the expected features of students who studied physics?
   - Which aspects of citizenship do we wish students to acquire by studying physics?
   - How can physics learning contribute to individual fulfillment?
   - How can we cooperate with other subjects to achieve general educational goals?
3. As Social Phenomena
   - How has physics been developed historically?
   - What are the interactions between physics and society?
   - How can everyday phenomena be explained through physics?
   - How would social phenomena be seen differently via physics?
4. As a means for Social Development
   - How can we identify and foster the gifted with physics?
   - How the principles of physics would be applied to technology & industry?
   - What do we need to do to make physics teaching more suitable for future scientists?
   - How the principles of physics would be applied to technology & industry?

   etc.

Particularly for teaching science as human culture and delivering Hearts-On science, one important group of the audience would be university students who do or do not major in science or engineering but want to learn more about science, society and culture. Table 6 illustrates possible contents of a 'Science Classics and Modern Society' course, in which a series of famous science classics of the 20th century are to be read and discussed by students with some help from short lectures by specialists of the field.

Ⅳ. Parallel Changes in Science Museums & Centres

Although the word 'museum' was originated from 'Museion', a place for the god of knowledge in Alexandria of ancient Egypt, its' modern sense of science museum was suggested during the 17th century. An English natural philosopher, Francis Bacon, proposed 'experiment' as the method for obtaining true scientific knowledges in his famous book, *New Atlantis*, and suggested to amass various objects for experiments. His idea was developed into 'Cabinet of

Table 6. Possible contents of 'Science Classics and Modern Society' Course

Science Classics	Examples of Topics to be Discussed
The Two Cultures (1959), by C. P. Snow	- personal experiences concerning Two Cultures - relationships between science, culture and education
A Mathematician's Apology (1940), by G. H. Hardy	- pure science vs. applied science - comparing Hardy's & Hogben's views of science
Silent Spring (1962), by R Carson	- environmental issues of modern science & technology - feminism movement in science
The Double Helix (1968) by J. D. Watson	- priority of scientific discovery and scientists' ethics - effects of cooperation in scientific research
Der Teil und das Ganze (1969) by W. K. Heisenberg	- epistemological issues of modern physics - science, religion, and scientists' responsibility
Patterns of Discovery (1958) by N. R. Hanson	- scientific objectivity and theory laden observation - generalization of scientific discovery process
What is Life? (1944) by E. Schrëdinger	- interplay between physics and biology - quantum mechanic's world view & life
The Structure of Scientific Revolution (1969) by T. S. Kuhn	- relationship between the history of science and the philosophy of science - possibility of scientific rationality & objectivity
Chance & Necessity (1970) by J. L. Monod	- atheistic humanism in science - scientists' philosophical reflection
Gaia (1979) by J. Lovelock	- scientific interpretation of myths - scientific discovery, analogy, and creativity
Against Method (1975) by P. Feyerabend	- importance of freedom in scientific thinking - individual difference in school science education
Science and Civilisation in China (1954-95) by J. Needham	- absence of modern science in Asian cultures - socialist scientists and their views of science
Entrophy (1980) by J. Rifkin	- credibility of non scientist's scientific arguments - applying scientific concepts to sociological phenomena
Surely You're Joking, Mr. Feynman! (1985) by R. P. Feynman	- moral position of a talented scientist - the joy of science and the condition of scientific discovery

Curiosities' in England and 'Wonder-Room' in Germany during the 18th century.

Owing to several individual collectors, like Ashmole and Sir Hans Sloane, a number of science museums opened their doors by showing science related special objects. They used to invite a limited number of guests to their houses and told them interesting and exotic stories on outside worlds. In particular, King George III of England was an enthusiastic collector of scientific apparatus with a great passion. Many valuable old exhibits of today's London Science Museum were the parts of 'King George III Collection of Scientific Apparatus' obtained from that time (Cho, 2001).

In February, 1683, Robert Plot, author *of The Natural History of Oxfordshire*(1677), alchemist, chemist, and antiquarian, arrived in London to assist Elias Ashmole with crating up his extensive collection of 'natural curiosities' and 'rarities'. Tradescant's Ark at Ashmole's house in Lambeth was a delightful place for a decade before it moved on to the Ashmolean Museum, Oxford. This Ashmolean, the first public museum in Britain, was not an arts museum at all, but celebrated the new scientific outlook of the Renaissance. It was intended for 'the knowledge of Nature' acquired through 'the inspection of Particulars' (Hackmann, 1992, p.65).

As the Industrial Revolution was in progress during the 19th century, various industrial machine tools, models and inventions were added to science collections of exotic specimens of animals and plants and of scientific apparatus. Scientific collections became much richer, and from this the Science Museum of London was born in 1876, after the international exhibition of the 'Special Loan Collection of Scientific Apparatus'. The Special Collection played a crucial role in connecting science and people by arranging various scientific programmes for different visitors (Cho, 2001).

This kind of eyes-on concept of science museum was changed into more interactive hands-on science museums during the first half of the 20 century. The Deuches Museum of Germany introduced a new way of exhibiting objects, dioramas, for the first time, and the Science Museum of London opened the 'Children's Gallery' with some interactive exhibits during the 1930s. However, this was mainly the age of the 'science museum', when the traditional science museum, such as the Science Museum of London and the Deuches Museum, mainly played the function of collecting, preserving and exhibiting the objects and exhibits based on the eyes-on concept (Cho, 2001).

The Exploratorium of San Francisco set up by Dr. Frank Oppenheimer during the 1960s was entirely based on hands-on concept of science museum. F. Oppenheimer, an atomic physicist involved in the 'Manhattan Project' with his brother, Robert Oppenheimer, decided to concentrate on conveying scientific concepts to visitors of all ages and all background. He and his staff aimed at developing new exhibits which would surprise visitors with whatever would arouse their curiosity. He brought the exhibits out from the showcases and dioramas and made them to be touched. Now, a new era of science center was begun, and hands-on science became a permanent feature of other museums in the 1980s and 1990s (Butler, 1992).

There have been, however, some criticism about the hands-on concept of science museum. Although hands-on science centers encouraged the visitors to have interest and entertainment with science, that was all (Bunnett, 2000). In other words, it has been reported that visitors who tried the exhibits actually have got very little scientific knowledge through the experience. A new concept of science museum, minds-on science museum, appeared, where hands-on exhibits are an important part of activities in the museum or centres. A series of connected activities to hands-on exhibits and presenters or explainers were introduced to help the visitors to understand the scientific principles of the exhibits. This minds-on movement in the field of science museums and centres has been influenced by the emergence of new philosophical arguments, such as constructivism and postmodernism (Hooper-Greenhill, 1994a; Hein, 1994). Along with minds-on and constructivist realization, there is recently a growing agreement that science museums need to be a centre of scientific communication and that museum pedagogy needs to be a part of the construction and reconstruction of culture (e.g. Hooper-Greenhill, 1994b).

The constructivist view of science museums, however, is largely limited to the intellectual and cognitive aspects of the role of the museums. People do not always go to science museums or centres to learn something, but they also go there to feel, to enjoy, to experience, and to participate in the culture of science. In this sense we believe that museums and centres need to be the place where people can meet and share 'hearts-on' science.

V. Conclusions

In this paper, to review the overall historical change of science education, we proposed a framework consisting of a series of analogies relating the parts of the human body with the features of science education of certain periods of the time. The pattern can be summarized as follows: Ears-On → Eyes-On → Hands-On → Minds-On. In addition, as a new paradigm of science education, Hearts-On, is suggested and some discussions and examples explaining the new analogy are given.

It is true that this kind of characterizing with analogies inevitably has some degree of over-simplification, as mentioned earlier. As the minds-on approach is not excluding hands-on activities but rather focusing on conceptual understanding which had been largely neglected in the earlier period, the hearts-on also does not exclude the key elements of the past paradigms. That is why the 'Hearts-On' approach encompasses the broad spectrum of six goals: understanding, joy, feeling, experience, awareness and participation. However, it is also important to look closely at the main features of the new paradigm, which would give us basically different visions of science education: that is, science as a culture, scientific humanism as a background philosophy of science education, and context as the focus of science teaching.

The new paradigm might be seen as another slogan for promoting the currently popular aim of science education, scientific literacy. It is not untrue that the 'Hearts-On' approach considers 'scientific literacy' as the essential theme of science education. But its primary emphasis is to provide a general framework and visions for the development of science education through which not only ordinary citizens but also future scientists are to be fostered. The six goals, particularly to feel the beauty of science and to participate in the development of science, are essential for both groups of students. Practically more important is how to provide a general environment of school science so that each group of students with different personal perspectives can pursue their own style of science learning. To this end, the differentiation of science curriculum and pedagogical approach according to students' interest and aptitude needs to be implemented, specially for older groups of the secondary level.

In his critical discussion on current school science, Jenkins(2000) emphasized three broad aspects of students' scientific inquiry: the engagement of the hand and mind in investigating the natural world, the contribution to students' intellectual and moral development as citizens in a democratic community, and their values and sense of ownership of what they do. It is believed that the 'Hearts-On' science education does encompass the main ideas of Jenkins and, at the same time, provide some concrete suggestions, as well as a wider framework for the future development of science education.

These days, physics in Korea is facing a tough issue of losing its traditional customers rapidly. At universities, introductory physics courses are largely ignored by a majority of students, including those of engineering and medicine schools. Most of the departments of physics are suffering from severe under-enrollment. At secondary schools, physics (and other science subjects) recently became classified as selective subjects with giving more freedom to choose to individual schools and students, and very likely high school physics would be taken by only less than 10% of the population.

The situation is not limited to physics. Science in general is widely unwelcomed by students. In 2001, the number of student who applied for the science-stream in the national matriculation examination became less than a half of that for the humanity-stream. The ratio of the applicants for the science-stream changed from 42.6% in 1994 to 26.9% in 2001, while that for the humanity-stream changed from 48.3% in 1994 to 56.4% in 2001, and that for the art/sport-stream from 9.1% in 1994 to 16.2% in 2001.

Although this rapid decrease of science-stream student population is particularly alarming in human power-driven economy systems like Korea, the situation seems rather universal across the world. In modern society, people are more and more inclined to cultual activities and they seem to be less and less attracted by science which still has strange, untidy, isolated and dark images (Newton & Newton, 1992; Song & Kim, 1999). The negative images toward science and the decline of the population of science-stream could be reduced by introducing more context-based approaches and by adopting more culturally relevant contents (e.g. White, 2001).

Of cause there is no one rigid way of doing science and science might be best developed with no external factors and constraints, as argued by Feyerabend(1975). Similarly, there should be no single way to help students study science, and as diverse as possible ways for encouraging them to study science need to be practised. Our belief is that when students can enjoy the joy of science, feel the beauty of science, experience the usefulness of science, be aware the responsibility of science, participate in the development of science, that is through Hearts-On science, they can best learn science. When this Hearts-On science is achieved, the gap between science culture and humanity culture, pointed out by C. P. Snow, more than a half of the century ago, could be practically reduced.

> Once or twice I have been provoked and have asked the company (highly educated) how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: *Have you read a work of Shakespeare's?* (C. P. Snow, *The Two Cultures*, 1959, p.15)

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