The Development of an Instrument for Assessing Secondary Students' Views on the Nature of Science

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과학의 본성에 대한 중등학생들의 견해 조사를 위한 도구 개발

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적 요

오랜 동안에 걸쳐서 과학의 인식론과 사회학에 관련된 주제를 대상으로 학생들의 이해를 측정하는 표준화된 여러가지 조사 도구들이 사용되어 왔는데 이러한 조사 도구들의 진술이나 선다형 선택지는 연구자들의 입장에서 제시된 경향이 있으며, 설문에 대한 응답에서도 연구자들이 요구하는 방식으로 학생들이 인지하고 해석하는 결점을 지적 받아 왔다. 학생들의 입장을 반영하여 경험적으로 만들어진 문항을 사용함으로써 조사 도구의 모호성에 대한 근본적인 문제점을 효과적으로 줄일 수 있다는 선행 연구들을 토대로 본 연구에서는 과학의 본성에 대한 학생들의 이해를 효과적으로 측정할 수 있는 새로운 조사 도구를 개발하였다. 본 조사 도구는 특정 이론에 의해서가 아니라 학생들에 대한 면접 결과를 바탕으로 한 과학적 검사와 실제 경험에 기초하여 5단계 과정에 의하여 개발되었으므로 과거에 개발되었던 조사 도구들과는 근본적으로 차이가 있다. 일반적으로 과학 교육 연구자들에 의해 받아들여지고 있는 과학의 본성에 대한 측면을 과학의 목적, 과학적 탐구의 본질, 과학 지식의 본질과 위상, 그리고 과학 공동체의 본질과 기능으로 규정하고 이에 대한 학생들의 관점을 파악할 수 있도록 설문의 내용을 세 영역 즉, "과학적 질문을 구성하는 특성", "탐구 실험의 특성", 그리고 "과학 지식을 주장하는 믿음에 대한 근거"로 구성하였다. "과학적 질문을 구성하는 특성"에서는 학생들이 제시된 네 종류의 질문에 대하여 과학적 질문인지 여부를 선택하고 그에 대한 정당한 이유를 밝히도록 하였고, "탐구 실험의 특성"에서는 피험자가 제시된 네 종류의 활동이 실험인지 여부를 선택하고 그렇게 선택하는 정당한 이유를 밝히도록 하였으며, 그리고 마지막으로 "과학 지식을 주장하는 믿음에 대한 근거"에서는 제시된 두 가지 친숙한 이론의 믿음 여부에 대한 정당한 이유를 밝히도록 구성되었다.

Key words : student understanding of the nature of science, investigative instrument

I. INTRODUCTION

The development of students' conceptions of the Nature of Science has been a concern of

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science educators for over 30 years. Actually, the inclusion of nature of science as a prominent instructional objective in the science curriculum can be traced back to the early 1900's (Central Association of Science and Mathematics Teachers, 1907; National Society for the Study of Education, 1960). Until recently, attention to students' understanding of science has focused on traditional science content (Driver, 1988; West & Pines, 1985). However, content related to the nature of science is receiving increased attention because of an interest in teaching science through a science-technology-society (STS) approach and teaching science in concert with the history and philosophy of science (Gruender & Tobin, 1991; McComas *et al.*, 2000; Posner & Strike, 1989; Solomon *et al.*, 1994).

For secondary school students, we see a reason why the development of images of science is particularly important. There is growing evidence that students' actions during science-learning tasks are influenced by their ideas about the nature of scientific knowledge (Edmundson & Novak, 1993; Lucas & Roth, 1996; Songer & Linn, 1991).

The persistent obsession with the nature of science by both researchers and policy makers is a direct consequence of the vast number of research investigations that consistently indicate that students, as well as teachers, do not possess what are considered to be adequate conceptions (Aikenhead, 1987; Lederman, 1992; Lederman & O'Malley, 1990; Wade & Lederman, 1995). Educators who plan science lessons, who develop science curricula, or who evaluate learning, often wonder about students' preconceptions of the materials to be taught.

Studies have been undertaken of school students' images of science and the significance of these findings for teaching and learning science in schools (Carey *et al.*, 1989; Driver *et al.*, 1996; Lederman, 1992). Other studies have taken place to assess students conceptions of the nature of science (Aikenhead, 1972; Carey et al., 1989; Rubba & Anderson, 1978; Tamir, 1994). For example, Rubba and Anderson (1978) developed and validated an instrument called a Model of the Nature of Scientific Knowledge(NSKS) to assess secondary school students' understanding of the nature of scientific knowledge. Further instruments have been developed since the NSKS(Gilbert, 1991; Lederman, 1986; Lederman & O'Malley, 1990). Studies have also taken place to develop, use, and assess curricula designed to improve students conceptions of the nature of science (Aikenhead, 1979).

Several standardized instruments have been used over the decades to assess student understanding of topics related to the epistemology and sociology of science (Aikenhead *et al.*, 1987). However, those instruments have been used with the erroneous assumption that students perceive and interpret the test statements in the same way as researchers do. This assumption of no ambiguity has been a traditional problem for science education researchers (Aikenhead, 1972; Gardner, 1987; Lederman & O'Malley, 1990). Ambiguity undermines test validity (Roid & Haladyna, 1981). In a more recent study of students' views on the tentativeness of science, Lederman and O'Malley (1990) identified the problem of language when they concluded, "Language is often used differently by students and researchers and this mismatch has almost certainly led to misinterpretations of students' perceptions in the past". Therefore, the original problem of ambiguity (researchers assuming that there is no ambiguity) can be effectively diminished by using empirically derived, Likert-type items.

The purpose of this study was to monitor students' understanding about the nature of science by the use of previous study that was performed by Driver *et al.*(1996), and to develop a new generation of standardized instrument that the original problem of ambiguity can be effectively diminished by using empirically derived students' responses to some general features of the nature of science.

II. THEORETICAL BACKGROUND

The current high level of interest among science educators in teaching about the nature of science reflects the view that this aspect of science is important and should be treated explicitly. But why do we consider it important that school students learn something of the nature of science? What would we wish students to know about the nature of science? These questions are very important.

Any answer to the question 'Why should students learn about the nature of science?' depends, of course, on the answer to a prior question 'Why should students learn science? Even though one important reason for the question is the perceived need to maintain a pool of qualified people from whom the scientists, technologists and technicians of the future may be drawn, for the majority, science is part of their general education- one aspect of their preparation for life. The aim here is to improve scientific literacy: that is, increase the numbers of 'scientifically literate' adults in society and hence to improve public understanding of science. We will therefore be considering the question 'Why does understanding of the nature of science matter?' from the perspective of a science curriculum which aims to provide access to basic scientific literacy for all students and hence to improve public understanding of science.

The core of the argument is that an understanding of the nature of science is an essential aspect of public understanding of science (McComas *et al.*, 2000). While improving 'scientific literacy' and hence 'public understanding of science' are widely advocated as educational goals, there is less argument about what, precisely, a person would need to know, understand or be able to do, to be regarded as 'scientifically literate', or about precisely what aspects of science we might wish the public to 'understand'. The Royal Society (1985) proposes that: 'Understanding includes not just the facts of science, but also the method and its limitations as well as appreciation of the practical and social implications. In Science for all Americans, the AAAS (1989, 1993) proposes a learning programme which encompasses a formidable range of content, spanning the physical and life sciences, technology, engineering and mathematics. The programme also includes an understanding of the nature of science, of mathematics and of technology, and the development of scientific 'habits of mind'.

In declaring an interest in probing students' representations of science, we are faced with the task of identifying which aspects of the nature of science are to be focused upon. We have chosen to base our investigation around key features which are generally accepted as characterizing the scientific enterprise.

We wished to base our exploration of students' ideas about science on those key ideas and constructs which are widely seen as central to the scientific enterprise:

1. Science is about explanation. Scientific knowledge is the product of our efforts to explain events and phenomena.

2. Two key ingredients of scientific explanations are generalizations(or laws) and theories.

3. Theories and universal generalizations are always underdetermined by data. That is, proposing a universal generalization or a theory always involves going beyond the available data. Universal generalizations and theories are inevitably conjectural.

4. Empirical data is the final test of scientific laws and theories. In many sciences this is collected through planned interventions, or experiments. In some sciences, experiment plays a less prominent role and detailed observation is more important.

5. Science limits its area of interest to phenomena which are taken to occur in the way that they do, regardless of the wishes or desires of the subject(s) of an investigation or those of the scientists conducting it.

6. Scientific knowledge is the product of a community, not of an individual. Findings reported by an individual must survive an institutional checking and testing mechanism, before being accepted as knowledge.

All those who have written about public understanding of science agree that it involves at least four aspects (Driver *et al.* 1996; McComas *et al.*, 2000; Trowbridge *et al.*, 2000) and in designing a study of students' ideas about science, therefore, we were interested in:

1) The purposes of the scientific enterprise;

2) The nature of scientific enquiry;

3) The nature and status of scientific knowledge;

4) The nature and functioning of the scientific community.

We see these features as being useful in helping us to frame the field of study and in identifying specific areas of interest within that field. We also acknowledge that the features are closely related and that in probing particular aspects of students' thinking about the nature of science, issues relating to more than one features are likely to arise.

1. Aspects of the nature of science to be investigated

1) The purposes of the scientific enterprise

This feature focuses on students' understandings of the purposes of the scientific enterprise and its domains of applicability.

Science is about explanation and control of the natural world; scientific knowledge is the product of our efforts to explain and control events and phenomena. Science limits its areas of interest to those events and phenomena which are taken to occur in the way that they do, regardless of the wishes or desires of the scientists investigating them, or those of the subject(s) of the investigation. Two key components of scientific explanations are generalizations (or laws) and theories (or models).

In this domain the following question is focused upon relating to aspects of students' perceptions of the purposes of science:

- What do students see as characterizing the kinds of questions which science addresses?

2) The nature of scientific enquiry

This feature focuses on students' representations of the procedures through which scientific knowledge claims are made, whether by professional scientists in the course of their work or by school students during science lessons. It deals with the context of discovery in exploring students' perceptions of the processes which are used in advancing scientific knowledge and the reasons for adopting them.

In generating new knowledge claims, scientists working within different scientific traditions employ a range of methods of enquiry. Many sciences depend heavily upon experimentation, in which part of the natural world is manipulated to obtain data. The collected data might be used in the evaluation of a theory, alternatively the data might simply offer further information about the phenomenon of interest. Whilst many sciences are based upon the planned interventions of experimentation, other sciences depends upon observation in generating new knowledge. Together, observation and experimentation are central to science. In the process of experimentation, observation and theory cannot be disentangled: one is symbiotic with the other.

In this domain we focus upon the following questions relating to aspects of students' perceptions of the nature of scientific enquiry:

- What do students see as being the purpose of experimentation?
- What do students see as characterizing the process of experimentation?

3) The nature and status of scientific knowledge

This feature focuses on students' understandings of the nature and status of scientific knowledge.

Theories and universal generalizations are always underdetermined by data and are therefore conjectural in nature. They deal with simplified, idealized systems and application to real world phenomena may therefore be problematic. Although theories and generalizations may develop and change with the passage of time, certain core theories, within a domain of science, are taken as agreed and not open to question. The preferred theories of the scientific community explain a wide range of data, are internally consistent, are simply stated, and do not respond to anomalies by *ad hoc* modifications.

In this domain we focus upon the following questions relating to aspects of students' perceptions of the nature and status of scientific knowledge.

- How do students understand the status of theories and their relationship to phenomena? To what extent do they see theories and generalizations as being conjectural?
- What warrants (if any) are drawn upon by students to justify their belief or disbelief of theories?
- How do students think that theories are evaluated? What role do they think that empirical evidence plays? Are students able to evaluate theories irrespective of whether or not they believe the theory?
- Do students differentiate theories from the phenomena which they explain in evaluating theories with empirical evidence?

4) The functioning of the scientific community

This feature focuses on how students view the nature and working of the scientific community, whether in terms of individuals, groups or whole communities. It deals with the context of justification of knowledge claims in exploring students' perceptions of how knowledge claims might be generated and supported in the scientific community.

Scientific knowledge is the product of a community, rather than of individuals. Findings reported by an individual or small group must survive an institutional mechanism of validation before being accepted as knowledge. There is thus a social component to the internal workings of the scientific enterprise. Scientific communities are also subject to external social factors. Societies' problems and interest groups influence the areas in which scientific advance is made; although science can contribute information to particular problem areas it offers only one perspective in making judgments.

In this domain this study focuses upon the following questions relating to aspects of students' perceptions of the functioning of the scientific community:

- To what extent do students see the scientific enterprise as a social endeavor?
- How do students interpret conflicts in ideas within the scientific community? How do they see these being resolved?
- How do students interpret the influence of society at large on the generation of scientific knowledge and the application of this knowledge in actual contexts?

III. DEVELOPMENT OF INSTRUMENT

1. Methodological issues

We are interested here in students' ideas about science and scientific knowledge, rather than the concepts that they use to explain particular phenomena. These aspects of students' thinking are rather subtle in character, and are often implicit in actions, rather than explicitly stated. Thus investigations of students' understandings of the nature of science differ in terms of both the methods adopted and the contexts in which the investigations are set.

One basic distinction in methodological approach lies between those studies which compare students' reasoning to pre-defined views of the nature of science (nomothetic) and those which explore the contents of students' reasoning in their own term (ideographic). An important alternative approach to these direct methods of questioning about the nature of science involves probing what might be termed students' epistemologies in action. Here the students' implicit ideas about the nature of science are probed by making inferences about their reasoning while they are engaged in specific activities. In this way, information about students' perceptions is obtained from their actions rather than through their explicit statements.

Just as the method of enquiry into students' ideas about the nature of science can be framed in a number of alternative ways, so too can the context for the enquiry. We can identify two principal ways of defining the context. Firstly, the context of enquiry might be defined in terms of how students conceptualize the nature of science and the work of scientists. Thus subjects might be asked to talk or write about their perceptions of the work that scientists do, the motivations for this work and the processes used by scientists for generating and evaluating explanations. An alternative approach acknowledges the likelihood that students may have little first-hand knowledge of the work of scientists, but that they have experience of the work they undertake themselves in school science. In this case the context for study is focused on students' understandings of the nature of the science knowledge and processes that they themselves encounter in school science lessons. Therefore it is quite possible that students' views of the nature of science in context of the work of scientists are different to those developed from their own experiences of learning science. This is an important distinction to be aware of selecting the context of enquiry.

In this study, firstly, we are taking a modified ideographic approach to probing students' thinking. We are interested in students' views on the nature of science in whatever terms they are expressed and with this in mind have developed a series of contexts in which students have the opportunity to make their thinking explicit. The present study is thus based upon an approach which involves designing tasks to be completed by students and then asking them to elaborate upon their actions and responses to questions in the context of the activity.

A further point to be made is that in probing the ways in which students manipulate scientific theories, we have selected theories that have a significant conceptual content. We are interested in the ways in which students relate theories to phenomena and events, in contexts similar to those that feature in the school science curriculum. A requirement which follows is that contexts need to be selected so that the conceptual content of theories is familiar and accessible to students across grade 8 to 10. We wish to minimize the extent to which students' abilities to express their thinking about the nature of science are constrained by their conceptual understanding.

2. Content

The instrument was developed from results of the ESRC project on students' understanding of the nature of science performed by Leach *et al.*(1996). Based on the coding scheme in the project, the questionnaire called Students' Understanding of the Nature of Science(SUNS) was developed by producing statements empirically derived from a sequence of students' interviews.

The questionnaire is composed with three sections, containing four parts in two sections and two in one, respectively. Each section is as follows :

1) Scientific Questions

The Scientific Questions probe is one of tasks designed to elicit the views of subjects about the purposes of science, the nature of scientific knowledge and enquiry, and the institutional practices of science. This prove was designed to examine the ways in which learners mark out science as a particular domain, and particularly the types of questions that they think are open to scientific investigation. Students will be asked to classify a range of questions on the basis of whether or not they are 'scientific questions' (a question that scientists would be interested to find out more about) and their justifications for the classifications are elicited.

From subjects' responses, analysis focuses on:

- students' ideas about the features which characterize questions as 'scientific' and 'not scientific'.
- the perceived limitations on the range of questions which can be addressed from a scientific perspectives.
- whether students believe that theories can be evaluated using empirical evidence.

2) Experiment

The Experiment probe is one of tasks designed to elicit the views of subjects about the purposes of science, the nature of scientific knowledge and enquiry, and the institutional processes of science.

This probe was designed to throw light on the ways in which learners may think about theories and their relationship to evidence in a range of contexts. A related aim concerns the sorts of activities that learners consider to be experiments, and their reasons for this. Subjects will be asked to classify particular activities taken from school science, real science and everyday contexts as 'an experiment' or 'not an experiment', and then asked to justify this classification.

From subjects' responses, analysis focuses on:

- what the students see as being the purpose of experimentation.
- the criteria used by students to characterize the process of experimentation.
- the idea which students have about the role of experimentation and empirical evidence generally in evaluating scientific knowledge claims.

3) Warrants for Belief

The Belief probe set out to explore students' grounds for accepting scientific proposition. We are interested to see whether students are able to articulate the grounds for their acceptance of a proposition and, if they are, to explore the nature of these grounds. We expect that justifications may be provided in terms of trust in certain authorities (parents, teachers, scientists, or adults in general), or in terms of evidence, either direct or indirect.

Subjects will be provided with a familiar theoretical proposition, asked whether they have heard of it before, and whether or not they believe it. In each case, their warrants for belief will be elicited.

From subjects' responses, analysis focuses on:

- the extent to which students see theories as being conjectural.
- the warrants which are drawn upon by students in justifying their belief or disbelief of theories.

All statements use a three responses format, with the usual choices of "agree", "disagree", and "not sure".

3. Procedures

The process took place in five steps.

As first step, the content for SUNS statements was defined by the generally accepted domain of the nature of science content appropriate for secondary school students. SUNS statements emphasize cognition (reasoned arguments) over affect (personal feelings). Attention was not given to students' feelings about traditional science content. Instead, SUNS statements focused on the reasons that students gave to justify an opinion - their informed viewpoints, their cognitive beliefs. The initial process of composing a SUNS statement followed coding scheme by the ESRC project because the instrument had already been validated. All the responses of students in the interviews of the ESRC project were written by coding scheme and classified, unifying duplicated sentence. Each statement was then typed into simple, clear words as much as, designated "first draft form".

As second step, the first draft form selected by the researchers was analyzed to discern common viewpoints or common justifications. Two evaluators who were educational specialists analyzed each statement by the coding scheme. The evaluators attempted to find common beliefs or viewpoints expressed by students. These common viewpoints were written in the students' language as much as possible. This phase was repeated more than 10 times. These common viewpoints were then edited so they conformed to a Likert-type format. This led to "second draft form".

Third step was to obtain empirical feedback on how well formed second draft of SUNS items captured the views that students were attempting to express in their statements. Approximately 20 secondary school students at grade 8 to 10 per item participated in a feedback interview to the revised SUNS statements: first, by underlying a statement which could not understand, second, by arguing the student positions in the second draft form, and then, third, by reaching an agreement in a reasonable statements. Therefore, the wording of the statements was revised for the validity of the instrument [to see further more, make reference to Aikenhead & Ryan' work (1992, p. 487)] and the item was polished into "third draft form".

As fourth step, the instrument was re-examined to ensure there was any problem on any item and statement and there was a satisfactory response spread by other two survey specialists. Before pilot test can be done, the English version of the form of SUNS was translated into Korean by the researchers. A back translation of the Korean version into English, by people not involved in the original translation, was then completed for content validity. At this stage, it was verified by English science educator that each statement retained its original meaning. This was a "fourth draft form".

The last step in the development of SUNS entailed pilot testing for the purposes of shortening a statement in each item by deleting students' justifications that received a very high response to "not sure"; and establishing baseline data against which the researchers could compare SUNS results about regional differences. About 150 students in three regions-metropolitan, small-sized city, and rural area- responded to the SUNS. Each statement of items in the forth draft form that had received little or no student response and that had not provided interesting feedback was eliminated. This shortened the length of the item as much as possible without losing variable information. The final form of SUNS was made by this step.

IV. CONCLUSION

The research project resulted in an assessment instrument dealing with the nature of science, Students' Understanding of the Nature of Science (SUNS). The instrument were developed empirically a six-month period with grade 8 to 10 students. SUNS' five-step development procedure is fundamentally different from instrument developed in the past. This difference is revealed by contrasting the conventional perspective of earlier instruments and the empirically derived character of SUNS. Within a conventional framework, researchers obtain test scores based on the fact that student responses are scored as correct or incorrect, or scaled in terms of a simple Likert-type response. SUNS, however, conveys students' ideas, not numerical scores. The possible statement to SUNS item derives not from a theoretical or researcher-based viewpoint but empirically from student viewpoints. Student responses to SUNS are qualitative data. Therefore, this feature guarantees the instrument's validity.

Several problems exist relative to teaching the nature of science. First, there are no specific descriptions of scientific literacy as these pertain to the nature of science. Second, no conceptual framework exists that describes teaching and learning strategies for the nature of science. Third, teacher understanding of content and pedagogy is weak. Several authors (Russell, 1951; Wagner, 1983; Duschl, 1985, 1988) have delineated these needs and problems. At this point, SUNS is a reasonably efficient tool for both curriculum planners and researchers as well as subject matter teachers. For curriculum planners and researchers, SUNS can serve as a departure for generating a custom assessment instrument to suit a particular STS curriculum or teaching situation; and as a framework for identifying major themes related to the nature of science, delineating a scope and sequence for developing student understanding of those themes, and providing recommendations for implementing the scope and sequence into science programs. At last, researchers are able to use the conceptual framework in curriculum planning and in developing suitable materials for STS. Science teachers find SUNS useful for initiating class discussions on the nature of science project. More over, science teachers can accurately assess their students' viewpoints on the nature of science. SUNS can be used wherever science researchers and teachers require an empirically generated and student-derived snapshot of students' views on issues concerning science-technology-society.

ABSTRACT

An assessment instrument dealing with secondary students' views on the nature of science was developed in this study. The features in aspects of the nature of science are generally accepted as characterizing the scientific enterprise and we have focused on are: 1) the purposes of the scientific enterprise, 2) the nature of scientific enquiry, 3) the nature and status of scientific knowledge, and 4) the nature and functioning of the scientific community. The questionnaire is made of three sections; that is, "Scientific Question", "Experiment", and "Belief". The Scientific Questions probe was designed to examine the ways in which learners mark out science as a particular domain, and particularly the types of questions that they think are open to scientific investigation. The Experiment probe was designed to throw light on the ways in which learners may think about theories and their relationship to evidence in a range of contexts. A related aim concerns the sorts of activities that learners consider to be experiments, and their reasons for this. The Belief probe was

designed to see whether students are able to articulate the grounds for their acceptance of a proposition and, if they are, to explore the nature of these grounds. The reliability of the instrument developed in this study was found to be 0.86.

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