Improving Epistemological Beliefs and Moral Judgment through a STS-Based Science Ethics Education Program

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Abstract

The present study was conducted to develop a Science-Technology-Society (STS)-based science ethics education program for high school students majoring in or planning to major in science and engineering. Our educational program included philosophy, history, sociology and ethics of science and technology, and other STS-related theories. The STS-based science ethics education program was expected to promote students' epistemological beliefs and moral judgment development. These psychological constructs are essential to properly solve complicated moral and social dilemmas in the field of science and engineering. We applied this program to a group of Korean science high school students gifted in science and engineering. To measure the effects of this program, we applied an essay-based qualitative measurement to the students. The results indicated that there were significant development in both epistemological beliefs and moral judgment. The need for developing epistemological beliefs and moral judgment utilizing STS-based science ethics education program is briefly discussed.

Keywords: Science-Technology-Society (STS), science ethics education, epistemological beliefs, moral judgment, moral development

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Education Program

Introduction

The purpose of this study is to develop a Science-Technology-Society (STS)-based science ethics education program for high school students majoring in or planning to major in science and engineering, and measure the effects of the course on students' epistemological beliefs and moral judgment development. Epistemological beliefs can be conceptualized as including beliefs about the nature of knowledge and the nature of knowing (Hofer, 2006; Hofer and Pintrich, 1997; Muis et al., 2006; Schommer, 2004). Moral judgment is a value-embedded judgment about how to behave in a certain situation, which is involved in conflicting values and interests (Sprigge, 1964). Indeed, these psychological constructs are significantly associated with the required virtues of scientists and engineers. First, most developed, sophisticated and constructivistic perspectives in the domain of epistemological beliefs are closely associated with the creativity (Klaczynsk, 200) that is strongly required to both scientists and engineers. The openness to novel experiences and criticism, and flexible perspective on complicated, conflicting scientific works, which are the aspects of the sophisticated epistemological belief (Greene, Torney-Purta and Azavedo, 2010), are essential source of the creativity (Davis and Rimm, 2004). Second, in the domain of moral development, more mature or profound moral judgment enables us to take other's perspectives, consider more complicated nature of moral dilemma, and present better solutions (Colby, Kohlberg, Gibbs, Lieberman, Fischer and Saltzstein, 1983). This highly sophisticated level of moral judgment is essential to properly make a moral decision in the field of science and technology, because a lot of conflicting social values and factors are involved in those kinds of problems (Bell, 1999; Bell and Lederman, 2003). Moreover, sophisticated

epistemological beliefs are significantly associated with moral judgment development, so we should pursue the development of both those two psychological constructs in scientists and engineers (Jeong, 2003; Bendixen, Schraw and Dunkle, 1998). Therefore, we should pay attention to the developments of those two psychological constructs and their interaction in scientists and engineers.

Hence, various STS theories including philosophy, history, sociology and ethics of science and technology that deal with complicated nature of science and science-society interactions would be beneficial to the development of both epistemological beliefs and moral judgment. These education contents oriented towards STS-based science ethics education may challenge students' previous epistemological and moral beliefs on science and technology, arouse inner cognitive conflicts and disequilibrium, and finally stimulate further developments. Thus, we designed and implemented a semester-long class of science ethics education for a group of Korean science high school students gifted in science and engineering. To measure the degree and level of development of students' epistemological beliefs and moral judgment on scientific and technological issues, we used an essay-based qualitative measurement.

Literature Review

Epistemological Belief Development

Psychological research on epistemological beliefs and reasoning has addressed six general issues: refining and extending Perry's (1970) developmental sequence, developing more simplified measurement tools for assessing such development, exploring gender-related patterns in knowing, examining how epistemological awareness is a part of thinking and reasoning processes, identifying dimensions of epistemological beliefs, and most recently, assessing how these beliefs link to other cognitive and motivational processes.

In all this research there is very little agreement on the actual construct under study, the dimensions it encompasses, whether epistemological beliefs are domain specific or how such beliefs might connect to disciplinary beliefs, and what the linkages might be to other constructs in cognition and motivation. However, Hofer and Pintrich (1997) noted that since the mid-1950s, there have been three simultaneous and intersecting lines of research which cut across the six general issues. Led by the initial work of Perry (1970), most researchers in the field have posited models that are to some degree structural, developmental sequences. One group has been largely interested in how individuals interpret their educational experiences (Baxter Magolda, 1987, 1992; Belenky, Clinchy, Goldberger and Tarule, 1986; Perry, 1970, 1981). Perry pioneered these endeavors with a sample that was almost entirely male; in response, Belenky et al. investigated "women's ways of knowing" with an exclusively female sample. Baxter Magolda, intrigued by gender implications of these two lines of research, chose to investigate similar concerns with both men and women.

A second group of researchers have been interested in how epistemological assumptions influence thinking and reasoning processes, focusing on reflective judgment (King and Kitchener, 1994; Kichener and King, 1981; Kitchener, King, Wood and Davison, 1989) and skills of argumentation (Kuhn, 1991, 1993). The theories and models differ somewhat depending on the focus of the inquiry and the populations studied, but there have been some points of convergence about what individuals believe knowledge is and how it is they know.

The third and most recent line of work has taken the approach that epistemological ideas are a system of beliefs that may be more or less independent rather than reflecting a coherent developmental structure (Hofer, 2006, Muis et al., 2006; Ryan, 1984a, 1984b; Schommer, 1990,

1994, 2004). These beliefs may influence comprehension and cognition for academic tasks, and this work has been the most concerned with classroom learning.

Schommer (1990, 1993a) suggested that multiple epistemic beliefs were related to adult cognition in several ways. Specifically, Schommer proposed five separate epistemic dimensions corresponding to beliefs about certain knowledge (i.e. absolute knowledge exists and will eventually be known), simple knowledge (i.e. knowledge consists of discrete facts), omniscient authority (i.e. authorities have access to otherwise inaccessible knowledge), quick leaning (i.e. learning occurs in a quick or not-at-all fashion), and innate ability (i.e. the ability to acquire knowledge is innate). Schommer's (1990, 1993a, 1993b) studies indicated that multiple epistemic beliefs (i.e. certain knowledge and quick leaning) were related to an ill-defined story-completion task, differ by gender, and developed in predictable sequence among adolescents.

Schommer (1990, 1993a) and Schommer and Hutter (2002) conceptualized these five dimensions of epistemological beliefs based on the perspective that one's beliefs not only about the nature of knowledge but also the nature of knowledge acquisition should be included in an epistemic model. As a consequence, the three dimensions of "certainty of knowledge," "omniscient authority," and "simple knowledge" represent one's beliefs about the nature of knowledge. The two epistemic factors showing beliefs about knowledge acquisition are "innate ability" and "quick learning."

Moral Development

The major developmental perspectives underlying the present education program and study derived from the theoretical writings of Lawrence Kohlberg (1969, 1971a, 1971b, 1975, 1976, 1981, 1984) and the modification of this theory by Rest and neo-Kohlbergians (1973, 1979; Rest, Narvaez, Bebeau and Thoma, 1999). Kohlberg (1975) asserted a sequential and

hierarchical development and articulation of moral reasoning extending from childhood into adulthood. His findings show culturally universal stages of moral development rather than relative values, and reflect developmental aspects as opposed to just learning rules or cultural mores. Stages are "structured wholes" or organized systems of thought, and imply qualitatively different modes of thinking, invariant sequence, and hierarchical integrations (Rich and DeVittis, 1994).

Moral stage development, in Kohlberg's (1981) model, requires the attainment of cognitive and perspective-taking prerequisites together with exposure to appropriate experiences of cognitive disequilibrium (Walker, 1988). Developing upward through the various stages, one's reasoning is increasingly concerned with others' needs and less exclusively with one's own. There is a development in capacity to deal with the increasing cognitive complexity and abstraction required to comprehend the reasoning of each successive stage.

Rest (1979) has argued that the question of the relation among developmental sequences in the various domains should not even be taken seriously. His reasons derive from his rejection of the strong Piagetian stage model. Rest agrees with Kohlberg's claim that qualitatively different forms of moral judgment can be identified and that developmental involves the increasing use of more advanced or sophisticated reasoning. He disagrees, however, with Kohlberg's claim that developmental proceeds through a stepwise sequence of internally consistent stages. He holds instead that individuals simultaneously use reasoning of many types and that an adequate description of an individual's moral judgment must include a quantitative account of the proportion of each type rather than a global designation for the person. Thus, Rest referred to the development process as schemas (soft, more permeable stages) rather than hard stages, as Kohlberg proposed (Rest, Narvaez, Thoma and Bebeau, 2000). Moreover, he and his school,

neo-Kohlbergians have insisted that cognitive moral reasoning cannot be the only element that predicts actual moral behavior. In addition to moral judgment based on cognitive processes, they suggested that moral sensitivity, moral motivation and moral character should accompany with the moral judgment to produce actual moral behavioral outcomes (Rest, 1994).

Class design for science ethics education

Our class was designed to promote students' epistemological belief and moral development, particularly their epistemological beliefs and moral judgmental ability on what they were studying—natural sciences and engineering. To achieve this purpose, we assure that our educational program includes appropriate educational interventions that cause student's development in four aspects (Han and Jeong, 2009, see Figure 1) : moral judgment to make a proper decision in complicated dilemma situations (Rest, 1994), moral sensitivity to detect implicit moral problems and imagine cause-and-effect chains (Rest, Narvaez, Bebeau and Thoma, 1999), epistemological beliefs to enable sophisticated and socio-interactive nature of scientific knowledge and scientific works (Han, 2006; Kuhn, 1996; Latour, 2005; Zeidler, Sadler, Simmons and Howes, 2005), and finally, metacognition on the relationship between science and society to understand sophisticated and complicated interaction between those two factors (Latour, 2005; Jost, Kruglanski and Nelson, 1998; Swanson and Hill, 1993).

[Place Figure 1 about here]

To improve epistemological beliefs and moral judgment including these four constructs, our program consisted of the following four steps that were proposed in Han and Jeong (2009)'s study. First, we introduced various contemporary theories in STS, including philosophy, history, ethics and sociology of science and technology, to our students. It was expected to provide students of opportunities of intellectual challenges, because it presents more sophisticated nature

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of science from more developed perspective than students' original perspective, arouse inner cognitive conflicts in students' reasoning, and then promote the development to higher level (Lapsley, 1996). Second, we attempted to link these STS theories to scientific and technological problems in real world. We introduced several dilemmatic cases from the field of natural sciences and engineering, and then applied previously introduced STS theories to these cases. It was expected to provide chances to think about decision making processes to students, while coping with real world problems. Moreover, this step would be particularly beneficial to students majoring in or planning to major in science and engineering, because these cases would coherent with students' own research interest and context of live, more strongly make sense to them, and much easier to attract their attention (Ozaktas, 2011). Third, we provided students of chances to evaluate STS theories and discuss issues in the field of science and technology from ethical perspective. The previous two steps were theoretical and lecture-based; however, students had chances to talk about real issues from STS and ethical perspectives by themselves. This activity-oriented step enables students to modify and develop their own perspectives and thinking processes. Finally, students had time to think reflectively about their belief systems and what they learnt and how they changed during whole class. To maximize the effects of educational intervention, it would be beneficial to contemplate and confirm newly formed moral beliefs and processes at the end of the class (Kirschenbaum, 2000).

According to this basic structure, we designed one-semester course for a group of Korean science high school students gifted in science and engineering. One-semester of sixteen weeks could be separated into two parts: first, introduction and lecture, and second, various activities including discussions and presentations. The first part consisted of seven weeks and dealt with introduction of STS theories and how to reinterpret and critically evaluate real scientific and

technological problems using the theoretical framework; they would correspond to the first two steps of our educational model—theory introduction and applying theory to real scientific problems. The contents of this first part are presented in table 1.

[Place Table 1 about here]

Then from week 8 to the end of the class, students were engaged in various student-oriented activities including discussions and presentations to actually apply the theoretical frameworks that have been taught in the first part. This second part corresponds to the third and fourth step of our educational model.

[Place Table 2 about here]

In addition to these classes, students took mid-term examination in week 8. It consisted of both short-answer and essay problems to confirm whether and not student were able to have properly learnt STS theories and related issues. Moreover, they were required to submit a reflection paper at the end of this course. Students had to choose and present one topic between week 9 and 15. Then, other students questioned and criticized their presentations. All students had to write a reflection paper based on those peer critics; they were required to think about how to answer those peer questions and critics, and how to improve their knowledge and understandings on the topic. Final grades were assigned between A and F, based on students' mid-term score, student presentation, final reflection paper and participation.

Method

Subject

A semester-long class of science ethics education started in mid-February, and ended in mid-June. Science high school students gifted in science and engineering took this class as a major-elective subject for two hours per week. There were thirteen male students and two female

students. All of them were in the eleventh grade, and were majoring in science and engineering —mathematics, physics, chemistry, bio science, earth science or computer science and engineering. They were selected as gifted students in the field of natural sciences and technology, when they entered this high school. Other than this class, they were usually taking some liberal arts classes—Korean, English, social studies, music, fine art, physical education, etc. —and major classes—calculus, dynamics, organic chemistry, etc.; they were taking these classes up to twenty hours per week in general.

Measurement

We measured students' epistemological beliefs and moral judgment levels using qualitative method—semi-structured essay writing. Students were asked to complete an essay dealing with the nature of scientific knowledge (for epistemological belief measurement) and moral dilemmas (for moral judgment measurement). This essay consisted of five questions, which can be separated into two parts—epistemological belief part and moral judgment part— and five questions in total. In the first part, there were three questions, and these questions were designed to measure students' development of epistemological belief—Simple Knowledge (SK), Certain Knowledge (CK) and Innate Learning (IA); the latter part that consisted of two questions aimed to measure students' moral judgmental ability in a scientific issue-related moral dilemma, and a general moral dilemma widely used for moral judgment measurement—the Defining Issues Test (DIT) designed by the neo-Kohlbergians (Rest, 1979). We requested students to complete this essay assignment at the beginning of the semester (pre-test) and the end of the semester (post-test). The students' essays were one to two thousand words long in general. Essay questions were (see Appendix for essay questions).

In total, fifteen papers were submitted their essays at both beginning and end of the semester. Among those fifteen responses, however, one student's response was omitted, because this student imprudently submitted his paper at the end of the semester that was identical to the previously submitted one. Thus, rest fourteen students' responses were being analyzed using qualitative method. First, before coding each student's response, we did segmentation on initial essay responses. We extracted segments from our raw data; these segments were chunks of students' responses, which contain independent meanings in themselves. Each segment was a basic unit of our coding process and further analyses (Emerson, Fretz and Shaw, 2011). And then, for further statistical analyses, we coded each segment according to our own coding scheme. This process enables us to conduct further quantitative analyses on students' essay responses by assigning numeric values to each segment (Scott and Morrison, 2006).

To analyze the answers for the first three questions, we referred to the epistemological belief theory proposed by Schommer (1990, 1994). The overall structure and format of each question was inspired by Epistemological Beliefs Inventory (EBI) that was invented by Bendixen, Schraw and Dunkle (1998) based on Schommer's five components model. Each of the first three questions corresponds to SK, CK and IA in Schommer's epistemological belief model. Omniscient Authority (OA) and Quick Learning (QL) were merged into the three questions. The first two questions that dealt with SK and CK partially entail aspects of OA. The third question was initially designed to correspond to IA, while partially dealing with QL. There was a psychological study regarding the relationship between individual components of the epistemological belief. Mason, Gava and Boldrin (2008) suggested that two dimensions of the epistemological beliefs—SK and CK—concern about the nature of knowledge, while the other two components deal with the nature of knowing and knowledge acquisition—IA and QL.

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Moreover, according to their study, the first component, the nature of knowledge can be divided into two smaller dimensions: the simplicity versus complexity (SK), and certainty versus complexity (CK) of knowledge. OA is assimilated into the nature of those two components regarding the nature of knowledge. Thus, we designed three questions, which correspond to the degree of the simplicity of knowledge, the degree of the certainty of knowledge, and the nature of knowledge acquisition, to measure our students' epistemological beliefs, based on Mason, Gava and Boldrin (2008)'s theoretical framework.

All of these three questions were designed to ask about the nature of scientific knowledge and scientific knowledge acquisition, because we intended to use these questions to measure science and engineering majoring students' epistemological beliefs in their fields; especially, we attempted to make this question entail some important topics in philosophy of science, such as the nature of scientific knowledge and "ways of knowing" in science (Bird, 1998). We assigned one of three numbers to each segment in students' responses for these three questions. 0 means the student believes scientific knowledge is simple and clear (SK), certain and stable (CK), and scientific abilities are absolutely innate (IA). We assigned 1, when the student thought that scientific knowledge is complicated and multifaceted (SK), uncertain and modifiable (CK), and we can acquire scientific knowledge and abilities through effortful practices (IA). Between 0 and 1, 0.5 means the student showed intermediate level of epistemological belief development between those two ends. A student score of each component was calculated by averaging all assigned numbers for the individual component. Therefore, calculated scores were ranged between 0 and 1.

Moreover, for analyses of the responses of two moral dilemmas, we utilized the coding method in Kohlbergian Moral Judgment Interview (MJI). Although there has been a quantitative

measurement for the moral development—DIT, subjects would not be able to generate their own free responses to a presented dilemma, because DIT is a recognition test that presents previously established options to the subjects. Unlike DIT, MJI enables the subjects to freely construct their own moral rations (Elm and Weber, 1994), so it would be more appropriate to investigate deeper and richer moral decision making processes. According to Kohlberg (1981, 1984)'s stage model of moral judgment development, we assigned the corresponding levels (1 to 5) of moral judgment to each segment. We utilized the basic idea of MJI coding methodology that was established by Colby and Kohlberg (1987). As we designed the first three questions for epistemological beliefs measuring, the fourth question was directly related to scientific and technological moral dilemma. This question was intended to deal with various ethical issues in the field of science and technology, such as micro- and macro-ethics in the context of engineering ethics (Herkert, 2001), research ethics dealing with ethical problems in research itself (Grinnell, 2012) and ethical problems related to broader social contexts (Doorn and Kroesen, 2011). Moreover, the last question, which was designed to measure students' moral judgment development in general, was extracted from a traditional Kohlbergian moral judgment measurement—DIT. All of these questions were designed to appropriately measure students' developmental levels in moral judgment. Because the prototype of these questions, DIT was well-designed to measure subject's moral judgment in complex social contexts, and to make a behavioral decision between conflicting values (Rest, Deemer, Barnett, Spickelmier and Volker, 1986), we also attempted to make our moral dilemmas include various conflicting values and alternatives. An individual student's judgment level of either scientific or general moral judgment was calculated by averaging all assigned level numbers in the student's responses to a particular question. Thus, calculated levels should be ranged between 1 and 5.

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Results

We first conducted t-test to compare students' pre and post-test scores in both epistemological belief components and moral judgment levels. The results of these t-tests are presented in Table 3 and Figure 2and 3.

[Place Table 3 about here]

[Place Figure 2 about here]

[Place Figure 3 about here]

The results of the t-tests show that there were statistically significant increases in all scores, SK ($t_{(90)} = 4.16$, $p < .001$), CK ($t_{(83)} = 3.34$, $p < .005$), IA ($t_{(82)} = 4.31$, $p < .001$), scientific moral dilemma ($t_{(63)} = 4.69$, $p < .001$) and general Kohlbergian moral dilemma ($t_{(64)} = 2.61$, $p < .05$).

[Place Table 4 about here]

After then, we conducted ANOVA to figure out which component was significantly more improved than other. First, we calculated each student's differences between pre- and post-test scores in each component. Then, we conducted two separated ANOVA for repeated measurements, one for epistemological belief components and another for moral judgment development. The result shows that there is statistically significant difference among increases in epistemological belief scores ($F_{(2, 39)} = 6.67$, $p < .005$). Moreover, the result of post-hoc analysis (Scheffe's test) shows that the increase in IA was significantly higher than that in both SK ($p < .05$) and CK ($p < .01$).

[Place Table 5 about here]

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In the dimension of the moral judgment level, we were not able to find a statistically significant difference between the increase in scientific moral judgment level and that in general Kohlbergian moral judgment level ($F_{(1, 26)} = 1.83$, n.s.).

Then, each student's individual pretest and posttest scores were compared to each other using t-test. The results on the comparisons between pretest and posttest epistemological belief components are presented in Table 6. First of all, in the dimension of SK, four students showed statistically significant increases at least $p < .1$ at two-tailed t-tests, seven students showed marginal increases, and two students showed marginal decreases. Students who showed statistically significant increases in SK were 1 ($t_{(6)} = 2.62$, $p < .05$), 3 ($t_{(5)} = 2.54$, $p < .1$), 8 ($t_{(5)} = 2.39$, $p < .1$), and 9 ($t_{(6)} = 4.9$, $p < .005$). Student 4, 5, 6, 7, 11, 12 and 14 showed marginal increases, and 10 and 13 showed marginal decreases, while all of those changes were not statistically significant. Second, in the dimension of CK, two students showed statistically significant increases at least $p < .1$ at two-tailed t-tests, five students showed marginal increases, and only one student showed a marginal decrease. Students who showed statistically significant increases in CK were 1 ($t_{(2)} = 3$, $p < .1$) and 3 ($t_{(5)} = 5.92$, $p < .005$). Student 7, 8, 9, 10 and 14 showed marginal increases, and 5 showed a marginal decrease, while all of those changes were not statistically significant. Because the standard deviation values of both pretest and posttest CK scores were zero for student 6, we were not able to conduct a t-test for this case, however. Lastly, in the dimension of IA, four students showed statistically significant increases at least $p < .1$ at two-tailed t-tests, two students showed marginal increases, and only one student showed a marginal decrease. Students who showed statistically significant increases in IA were 2 ($t_{(5)} = 2.07$, $p < .1$) , 5 ($t_{(5)} = 2.65$, $p < .05$) , 9 ($t_{(6)} = 3.27$, $p < .05$) and 10 ($t_{(2)} = 3$, $p < .1$). Student 4 and 8 showed marginal increases, and 7 showed a marginal decrease, while all of those changes

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were not statistically significant. Unfortunately, because the standard deviation values of both pretest and posttest IA scores were zero for student 6, 11 and 13, we were not able to conduct a t-test for them.

[Place Table 6 about here]

In addition, Table 6 shows the results of t-tests between pretest and posttest moral judgment levels according to Kohlbergian stage model. First, for scientific moral dilemma (M1), four students showed statistically significant increases at least $p < .1$ at two-tailed t-tests, seven students showed marginal increases, and only one student showed marginal decreases. Students who showed statistically significant increases in M1 were 6 ($t_{(3)} = 3.87$, $p < .05$), 10 ($t_{(3)} = 4.02$, $p < .05$), 11 ($t_{(4)} = 4$, $p < .05$), and 13 ($t_{(2)} = 3$, $p < .1$). Student 3, 4, 7, 8, 9, 12 and 14 showed marginal increases, and 5 showed marginal decreases, while all of those changes were not statistically significant. However, because the standard deviation values of both pretest and posttest M1 scores were zero for student 1 and 2, we were not able to conduct a t-test for them. Moreover, for general Kohlbergian moral dilemma (M2), two students showed statistically significant increases at least $p < .1$ at two-tailed t-tests, six students showed marginal increases, and no student showed a marginal decrease. Students who showed statistically significant increases in M2 were 7 ($t_{(3)} = 3.87$, $p < .05$) and 13 ($t_{(2)} = 3$, $p < .1$). Student 4, 5, 6, 9, 11 and 12 showed marginal increases, while all of those changes were not statistically significant.

[Place Table 7 about here]

Finally, we conducted mixed model ANOVA to appropriately figure out differences between pre- and post-test scores in our students. We set both the between-subjects variable (each student) and within-subjects variable (pre- vs. post-test).

$$y_{ijk} = \mu_{ij} + e_{ijk}$$

$$= \mu + A_i + B_j + (AB)_{ij} + e_{ijk}$$

In this model, y_{ijk} means the ith student's score for the kth individual segment at pre- or post-test (j, j = 1 for pre-test and 2 for post-test). μ_{ij} is an individual i^{th} student's mean score for either pre- or post-test (j). Finally, A_i stands for an individual student's factor, and B_i is a test factor. e_{ijk} represents an error term for each individual segment. The results show that there were significant differences between pre- and post-test scores in all measurements, SK ($F_{(1,13)} = 21.03$, $p < 0.0001$) CK ($F_{(1,13)} = 15.86$, $p < 0.0005$), IA ($F_{(1,13)} = 21.11$, $p < 0.0001$), scientific moral dilemma ($F_{(1,13)} = 23.31$, $p < 0.0001$) and general Kohlbergian moral dilemma ($F_{(1,13)} = 13.54$, $p < 0.001$) (see Figure 2 and 3).

Discussion

There were statistically significant developments in students' both epistemological beliefs and moral judgment. In the dimension of epistemological beliefs, STS theories that were challenging students' previous perspectives on scientific knowledge and scientific works might have promoted students' development. Philosophy of science deals with the nature of scientific knowledge and "ways of knowing" in science (Bird, 1998); history of science concerns about the complicated, non-linear process of the development of science, and shows us actual scientific processes through the historical records (Darrigol, 2007); and sociology of science deals with how science and society interact with each other, and how social factors influence the construction of scientific knowledge (Logino, 2011). Indeed, several studies have argued that reflecting activities upon previous beliefs (Brownlee, Purdie and Boulton-Lewis, 2001), high order thinking activities in educational experiences (Schommer-Aikins and Hutter, 2002), chances to think about the social construction of knowledge (Baxter Magolda, 2004), and talking about complicated ill-structured problems regarding the nature of knowledge (Hofer, 2001) are

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able to foster epistemological beliefs development toward more constructivist perspectives. Also, previous empirical study done by Han (2006) indicated that intensive engagement to STS classes induced statistically significant development in some parts of college students' epistemological beliefs, specifically CK. Hence, lectures and student-oriented activities that dealt with STS contents would have been challenging to students' previous perspectives and provided them of more sophisticated perspectives.

Moreover, this study would contribute to development of novel methodology to measure the effects of science ethics education programs. The initial empirical study conducted by Blatt and Kohlberg (1975) showed that vigorous moral dilemma discussion can lead to students' moral judgment development toward higher levels. Indeed, in the field of professional ethics education, there have been various studies that have shown significant moral development in students after ethics educational interventions. Nurse ethics education program promoted significant development in students' moral judgment and actual clinical practice (Duckett and Ryden, 1994); dental ethics education interventions resulted in significant development in dental students' both moral sensitivity and judgment (Bebeau, 1994); intentionally designed ethics education programs significantly increased moral judgment scores of medicine and veterinary medicine students (Self and Baldwin Jr., 1994; Self, Olivarez and Baldwin Jr., 1994); finally, a ethics education program for science and engineering majoring students that includes topic related to the responsible conduct of research (RCR) significantly developed students' perspective-taking ability, moral efficacy and moral courage (May and Luth, 2012). All of those programs were designed to fit into special interests of students; those programs utilized potential moral dilemmas in students' fields as class materials. Indeed, a previous study showed that STS applied courses were more effective than general ethics and philosophy courses to promote

science and engineering majoring students' moral development (Han, 2006), because STS materials are much closer to those kinds of students' research interests and contexts of lives than general "pure" humanities, such as general moral philosophy and history. (Ozaktas, 2011). This can be supported by some neuroscientific studies on the relationship between cultural norms and human self-concept. Even though self-concept in human brain would be influenced by cultural, environmental factors—may include education, actual self-concept development in human brain can occur when a person willfully, voluntarily and actively involves in those factors (Kitayama and Tompson, 2010); and neuroimaging studies have shown that self-referring activities, which are closely related to subjects' self-context, significantly more associated with prefrontal executive, memory encoding and recalling processes than other kind of activities (Craik et al., 1999; Kolley, Macrae,Wyland, Carglar, Inati and Heatherton, 2002; Johnson, Baxter, Wilder, Piper, Heiserman and Prigatano, 2002; Zhu, Zhang, Fan and Han, 2007). Hence, STS materials directly related to the interests of students in our science high school would be more effective than ordinary ethics courses for moral development. Moreover, as we did in our class, previous educational programs that were introduced above induced students' spontaneous discussions, and pursued their moral development through inner moral conflicts and reflections. It is coherent with the main point of Kohlberg and Blatt's (1975) study of effective moral education for moral development.

Hence, this study provides some implications for further research. First, this study would contribute to formulating an ethics education program for science and engineering students. Because we utilized STS theories and topics that directly deal with real science and technology issues in our curriculum, our program would be more attractive than traditional philosophical or ethics classes for science and engineering students; it would be the reason why our program lead

to significant and meaningful developments in students. Second, essay-based qualitative measurements that we used in our study would be helpful to further studies that attempt to measure the effects of science and engineering ethics education programs. We attempted to measure the effects of "science and engineering" ethics education program that focused on science and engineering topics, rather than general moral philosophical issues. Previous measurements that were targeting to measure more general domain of epistemological beliefs and moral judgment would not be able to properly figure out epistemic and moral developmental changes in scientific and technological domains. However, our essay questions were developed to fit into the context and life of science and engineering students, they will be proportionally beneficial to measure the effects of moral educational programs in the field of science and engineering. Even though we did not design a quantitative measurement that can be applied to large-group studies, our essay questions would be the candidates of questions in a quantitative measurement in further studies.

However, this study may contain some limitations. First of all, our study was not based on a true-experimental design; it used a quasi-experimental design—one group pre- and post-test comparison. Thus, we cannot be sure about whether or not the detected changes of students were totally originated from our educational program; or, other kind of factors, such as history and maturation (Campbell and Stanley, 1963). Moreover, because the size of this class was proportionally small ($N = 15$), this small sample size would negatively influence the reliability of the sample and generalization (Gould, 2002), and limit the power of our statistical analyses (Cohen, 1992). Indeed, we were not able to recruit a large group of students in our study, because our education program attempted to employ an innovative and experimental approach in one of the best science high schools for gifted students selected by the ministry of education of

Korea. As a result, the number of students in our class was limited, and it was difficult to recruit additional students out of our class to constitute the control group. Of course, because we used a deep essay-based qualitative method in our study, it would be hard to apply this kind of method to much larger group. However, to increase the generalizability of our study, it would be better to invent a quantitative measurement based on our essay questions, and apply it to much larger group in further studies. These points should be considered and solved in further studies on the effects of STS-based science ethics education.

Conclusion

In the present study, we developed a new STS-based science ethics education program for science high school students. Unlike previous, traditional moral philosophical classes, we attempted to introduce various STS theories including philosophy, history, sociology and ethics of science and technology that can well fit into students' interests and contexts of lives. We expected that these materials would significantly challenge students' existing beliefs on scientific knowledge and scientific works, and cause inner conflicts for further sophistication and development of their beliefs. In addition, because developed constructivist epistemological beliefs closely associate with sophisticated post-conventional moral judgment competence, the meaningful development in students' moral judgment is also expected. We applied this STS-based curriculum to a group of Korean high school students gifted in science and engineering for a semester. All of those students submitted intensive essays regarding their epistemological beliefs and moral judgment about scientific and technological issues for pre- and post-test. The results showed that there were statistically significant developments in students' both epistemological beliefs and moral judgment competence.

Our study attempted to design a new STS-based science ethics education program for science and engineering majoring high school students, and measure its effects using an essay-based qualitative measurement. Our study would contribute to enhance science majoring students' beliefs on sciences and moral judgment competence on scientific issues. Moreover, because our essay-based measurement particularly focused on scientific and technological issues rather than on general moral philosophical dilemmas that were used in traditional measurements, our method would be helpful to further studies on science ethics education program development. Although there were significant results and potential contributions in our study, it also contained some limitations; due to its small sample size and quasi-experimental design, the generalizability and reliability of the results would be limited. Hence, further studies should improve the research design, develop a new quantitative measurement based on our essay measurement, and apply this new design and measurement to much larger group to fix those limitations in the present study.

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Appendix

Essay Questions Used to Measure Epistemological Beliefs and Moral Judgment

Question for SK

Do you think science can simply and clearly explain everything? In other word, do you think science can show us right and wrong simply and clearly without any complexity? Why do you think so?

Question for CK

Do you think science can bring us certain and eternal truth? Why do you think so?

Question for IA

Do you think great scientists were born with innate abilities? Otherwise, they establish their own knowledge and abilities through endless and effortful practices? Why do you think so?

Question for science-related moral dilemma

I am a professor in a university, got a huge amount of research grant from a national foundation, and operate my own laboratory. Our team has been conducting a research project to discover a novel genetic material—Z—, since three years ago; we got one million dollars per year from the national foundation. We are on the last phase of our five years long project, however, a problem occurred. Although we expect that this new genetic material will contribute to drastic development in biotechnology in Korea, this new material would produce huge amount of pollutants during mass production. I think it is inappropriate to continue this research project with my good conscience. However, if we complete this project, Korea can compete with other leading countries in this field; moreover, we will be able to expand our research team with increased funding grant. If we report the side effect, and abort this project, we would lose a chance to compete with world-leading countries, and even worse, researchers in our team would

lose their positions. In this situation, what should I do? Should I continue this project? Or should I abort the project and report the side effect? Why do you think so?

Question for general Kohlbergian moral dilemma (extracted from Rest, 1979)

A man had been sentenced to prison for 10 years. After one year, however, he escaped from prison, moved to a new area of the country and took on the name of Thompson. For 8 years he worked hard, and gradually he saved enough money to buy his own business. He was fair to his customers, gave his employees top wages, and gave most of his own profits to charity. Then one day, Mrs. Jones, an ole neighbor, recognized him as the man who had escaped from prison 8 years before, and whom the police had been looking for. Should Mrs. Jones report Mr. Thompson to the police and have him sent back to prison? Why do you think so?

Table 1. *Topics in the first part of the class*

Week	Topic	Explanation
1	Orientation	Explain syllabus, Q&A
2	The nature of science (Philosophy of Science)	Introduce the results of philosophical inquires on the nature of science, especially nature of scientific knowledge. Based upon philosophical consideration, critically reevaluate students' previous perspectives on science.
3	The nature of scientific work (Sociology of Science)	Through sociological investigations on science, especially scientific processes and works. Critically reflect upon the society of scientists and the process of scientific works in real. In this week, consider the interactions between science and society.
4	Diverse issues (Feminism, Innovation and Leadership)	Introduce diverse perspectives on the nature of science from out of science. In this week, students critically reconsider traditional perspectives on the nature of science, which they might have had before.
5	Social responsibility of scientists	Based upon theoretical frameworks about new perspectives on science and the relationship between science and society that have learnt in week 2-4, consider how scientists and engineers' behaviors influence society, and what kind of responsibilities are required to them.
6	Case studies (Bio, Medicine and Research Ethics, etc.)	Applying the contents in week 2-5 to real scientific problems, such as bioscience, medicine and research ethics.
7	Scientific investigation on human morality	Explain the nature of human morality from scientific perspective by introducing contemporary scientific studies, such as fMRI and TMS studies. Present the results in cognitive neuroscience, sociology and other fields of natural sciences to pursue the consilience between various disciplines.

Table 2. *Topic in the second part of the class*

Week	Topic	Explanation
9	The nature of scientific knowledge	Scientific knowledge is always absolute, certain and reliable?
10	Value neutrality in science	Are scientific and engineering processes always value neutral?
11	Case study 1: Research Ethics	Malpractices in scientific research (e.g. data manipulation)
12	Case study 2: Bio Ethics	Moral dilemmas in bioscience studies (e.g. studies utilizing human embryonic stem cells)
13	Case study 3: Medicine Ethics	Moral dilemmas in medicine (e.g. abortion)
14	Case study 4: Cyberethics	Moral dilemmas related to the computer and internet (e.g. copyright vs. copyleft, hacking, cracking)
15	Scientific investigation on human morality	How natural scientific methods (e.g. fMRI, PET, TMS) can contribute to the studies on human morality?
16	General Discussion	Discuss all of previous topics

Table 3. *T-tests between pre- and post-test epistemological beliefs and moral judgment*

	N Pre-test	M Pre-test	SD Pre-test	N Post-test	M Post-test	SD Post-test
SK	44	0.50	0.39	48	0.80	0.04
CK	41	0.66	0.06	44	0.90	0.04
IA	42	0.58	0.07	42	0.90	0.04
Sci. Moral	36	3.64	0.13	29	4.52	0.14
Gen. Moral	32	3.59	0.13	34	4.06	0.13

Table 4. *ANOVA result of changes in each epistemological belief component*

	Mean Difference	Scheffe's Test
SK	0.30	ΔSK, ΔCK < ΔIA
CK	0.24	
IA	0.32	

Table 5. *ANOVA result of changes in each moral judgment dilemma*

|	Mean Difference	Scheffe's Test
Sci. Moral	0.88	n.s.
Gen. Moral	0.47	

Table 6. *Individual students' changes in epistemological beliefs*

No	Pre SK	Post SK	ΔSK	Pre CK	Post CK	ΔCK	Pre IA	Post IA	ΔIA
1	0.30	0.83	0.53[**]	0.25	1.00	0.75[*]	1.00	1.00	0.00
2	1.00	1.00	0.00	1.00	1.00	0.00	0.50	1.00	0.50[*]
3	0.00	0.75	0.75[*]	0.13	1.00	0.88[***]	1.00	1.00	0.00
4	0.83	1.00	0.17	1.00	1.00	0.00	0.83	1.00	0.17
5	0.17	0.33	0.17	0.33	0.00	-0.33	0.25	0.83	0.58[**]
6	0.50	0.75	0.25	0.50	1.00	0.50[†]	0.00	1.00	1.00[†]
7	0.40	0.75	0.35	0.40	0.80	0.40	0.88	0.75	-0.13
8	0.50	0.90	0.40[*]	0.83	0.90	0.07	0.75	0.88	0.13
9	0.00	0.80	0.80[***]	0.83	1.00	0.17	0.13	0.75	0.63[**]
10	0.50	0.25	-0.25	0.83	1.00	0.17	0.25	1.00	0.75[*]
11	0.67	1.00	0.33	1.00	1.00	0.00	0.00	1.00	1.00[†]
12	0.75	1.00	0.25	1.00	1.00	0.00	1.00	1.00	0.00
13	0.83	0.50	-0.33	1.00	1.00	0.00	0.83	0.75	-0.08[†]
14	0.75	0.90	0.15	0.75	1.00	0.25	0.90	0.90	0.00

Table 7. *Individual students' changes in moral judgment*

No	Pre M1	Post M1	ΔM1	Pre M2	Post M2	ΔM2
1	2.75	3.00	0.25†	5.00	5.00	0.00
2	4.50	5.00	0.50†	4.00	4.00	0.00
3	4.00	4.50	0.50	3.50	3.50	0.00
4	4.00	4.50	0.50	3.00	4.00	1.00
5	3.67	3.00	-0.67	3.33	4.00	0.67
6	3.33	5.00	1.67**	3.50	4.00	0.50
7	4.00	4.67	0.67	3.00	4.67	1.67**
8	3.50	4.50	1.00	4.00	4.00	0.00
9	3.50	4.00	0.50	4.50	4.67	0.17
10	3.00	4.50	1.50**	2.00	2.00	0.00
11	3.67	5.00	1.33**	3.67	4.00	0.33
12	4.33	5.00	0.67	4.00	4.50	0.50
13	3.00	4.50	1.50*	3.00	4.50	1.50**
14	4.33	5.00	0.67	4.00	4.00	0.00

*Figure 1.* Backgrounds and educational objectives of science ethics education
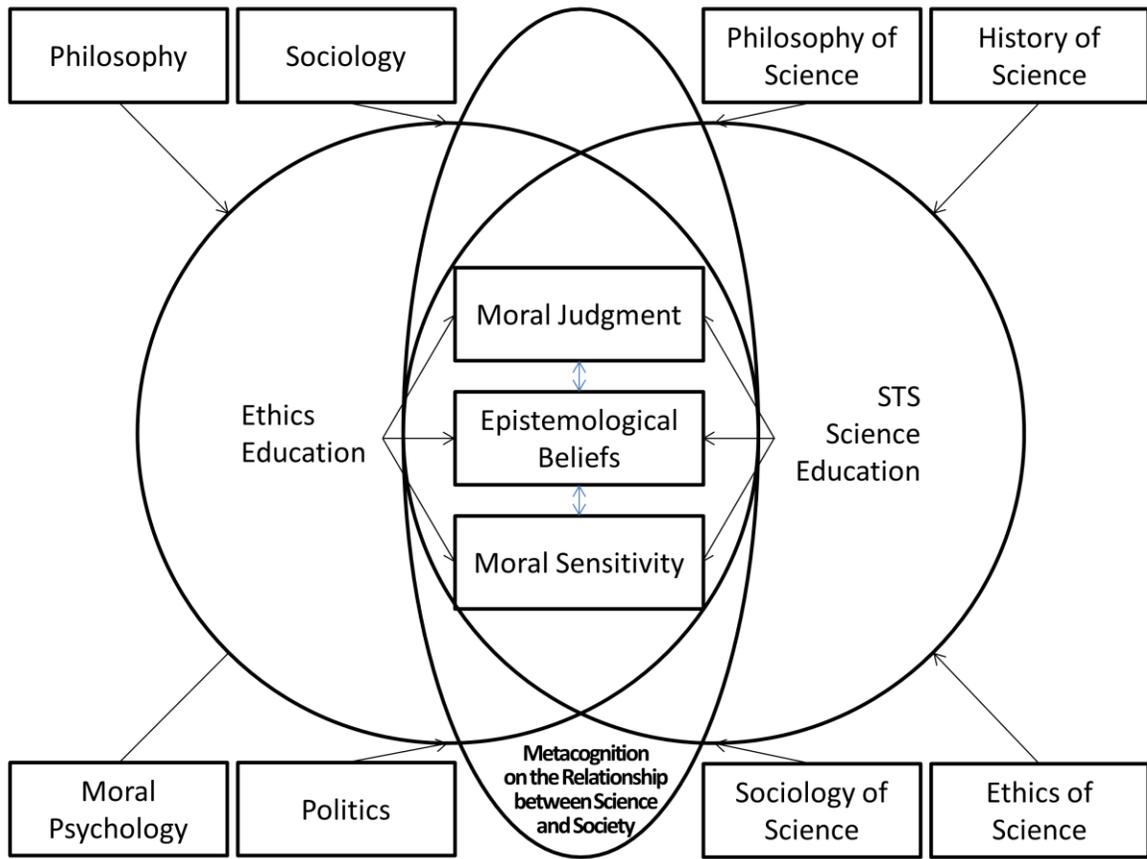
(Figure 1 → fig1.pptx for artwork, only in black and white)

Figure 2. Changes in students' epistemological beliefs
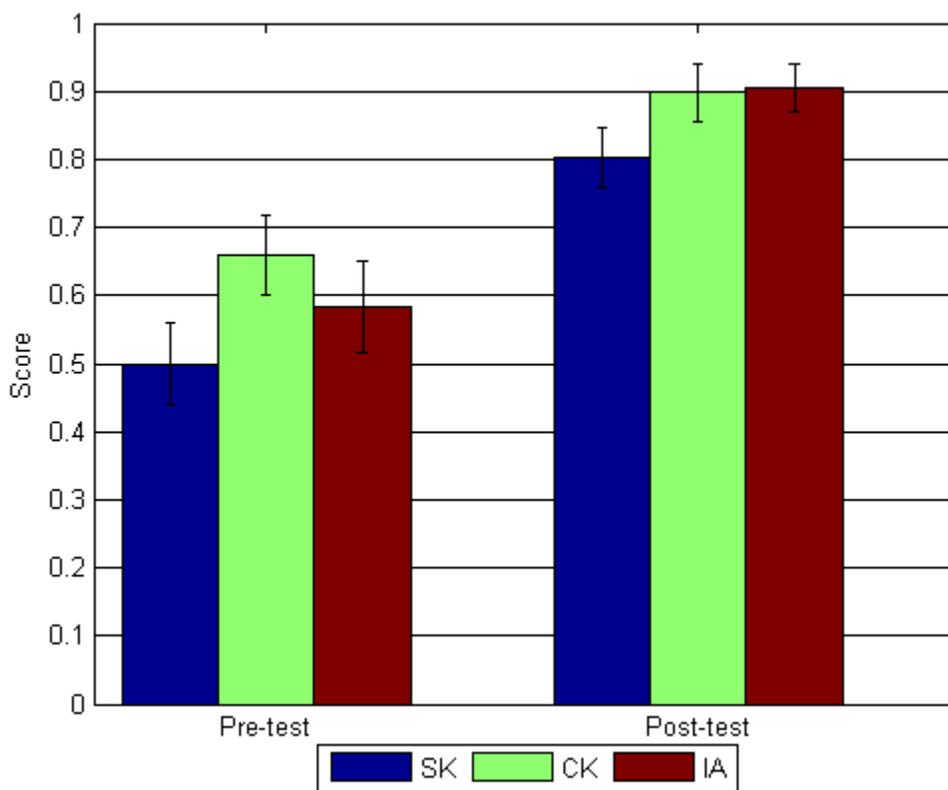
(Figure 2 → fig2.eps for artwork, color on the Web only)

Figure 3. Changes in students' moral judgment levels
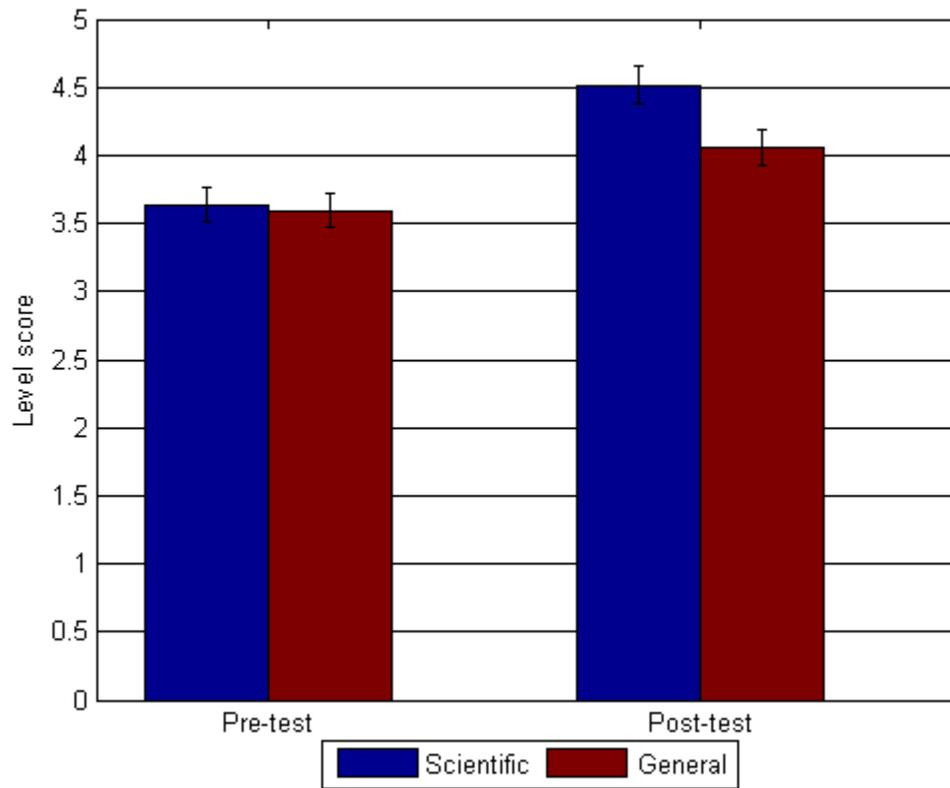
(Figure 3→ fig3.eps for artwork, color on the Web only)