Sci Eng Ethics (2014) 20:197–220
DOI 10.1007/s11948-013-9429-4

ORIGINAL PAPER

Improving Epistemological Beliefs and Moral Judgment Through an STS-Based Science Ethics Education Program

Hyemin Han · Changwoo Jeong

Received: 14 September 2012 / Accepted: 1 January 2013 / Published online: 22 January 2013

Abstract This study develops 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 education program includes the fields of philosophy, history, sociology and ethics of science and technology, and other STS-related theories. We expected our STS-based science ethics education program to promote students' epistemological beliefs and moral judgment development. These psychological constructs are needed to properly solve complicated moral and social dilemmas in the fields of science and engineering. We applied this program to a group of Korean high school science students gifted in science and engineering. To measure the effects of this program, we used an essay-based qualitative measurement. The results indicate that there was significant development in both epistemological beliefs and moral judgment. In closing, we briefly discuss the need to develop epistemological beliefs and moral judgment using an STS-based science ethics education program.

Keywords Science–Technology–Society (STS) · Science ethics education · Epistemological beliefs · Moral judgment · Moral development

H. Han (✉)
Stanford University School of Education, 485 Lasuen Mall, Stanford, CA 94305-3096, USA
e-mail: gksgpals@stanford.edu

C. Jeong (✉)
Department of Ethics Education, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-748, South Korea
e-mail: jcwwoo@snu.ac.kr

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 to measure the effects of the course on students' development of epistemological beliefs and moral judgment. Researchers often define "epistemological beliefs" as beliefs about the nature of knowledge and the nature of knowing (Hofer 2006; Hofer and Pintrich 1997; Muis et al. 2006; Schommer-Aikins 2004). On the other hand, "moral judgment" is a value-embedded judgment about how to behave in certain situations, specifically in the situations that represent conflicting values and interests (Sprigge 1964).

Researchers have shown that both of these psychological constructs are among the required virtues of scientists and engineers. First, most developed, sophisticated and constructive perspectives in the domain of epistemological beliefs are closely associated with the creativity that both scientists and engineers need (Klaczynsk 2000). For scientists and engineers, a sophisticated system of epistemological belief entails an openness to novel experiences and criticism and a flexible perspective on complicated and conflicting scientific works (Greene et al. 2010), both of which are an essential source of their creativity (Davis and Rimm 2004). Second, more mature or profound moral judgment enables individuals to take on others' perspectives, to consider the more complicated aspects of a moral dilemma, and to present better solutions (Colby et al. 1983). Because scientific and engineering works are often intertwined with conflicting social values and factors, this higher level of moral judgment is essential to properly make a moral decision (Bell and Lederman 2003). Moreover, researchers have linked both sophisticated epistemological beliefs and moral judgment development (Jeong 2003; Bendixen et al. 1998), and it has been suggested that we should attempt to develop both those two psychological constructs in scientists and engineers (Han 2006).

To help students develop more sophisticated beliefs about the nature of science and more mature or profound moral judgment, we can look to STS theories that draw broadly on philosophy, history, sociology, and ethics of science and technology and that address the complicated nature of science, the links and interactions between science and society, and the ethical issues arising from recent scientific and technological progress. 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, to improve students' epistemological beliefs and moral judgment, we designed and implemented a semester-long class on science and engineering ethics for a group of high school science students in Korea gifted in science and engineering. We used an essay-based qualitative test to measure the degree and level of development of students' epistemological beliefs and moral judgment on scientific and technological issues.

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 part of the thinking and reasoning processes, identifying the dimensions of epistemological beliefs and, most recently, assessing how these beliefs link to other cognitive and motivational processes.

In all of this research, though, there has been 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 that cut across these six general issues. Following the work of Perry (1970), most researchers in the field have posited models that are to some degree structural and developmental sequences. One group has been largely interested in how individuals interpret their educational experiences (Baxter Magolda 1992; Belenky et al. 1986; Perry 1970). 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 the gender implications of these two lines of research, chose to investigate similar concerns using both men and women.

A second group of researchers has been interested in how epistemological assumptions influence the thinking and reasoning processes and has focused on reflective judgment (King and Kitchener 1994) and argumentation skills (Kuhn 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 they believe knowledge comes to be known.

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 the reflection of a coherent developmental structure (Hofer 2006; Muis et al. 2006; Schommer-Aikins 2004). These beliefs could influence comprehension and cognition in academic tasks, and, as a result, this work has focused most predominantly on classroom learning.

Schommer-Aikins (2004) has suggested that multiple epistemic beliefs are related to adult cognition in several ways. Specifically, Schommer-Aikins proposed five separate epistemic dimensions corresponding to beliefs about certain knowledge (CK) (i.e., absolute knowledge exists and will eventually be known), simple knowledge (SK) (i.e., knowledge consists of discrete facts), omniscient authority (OA) (i.e., authorities have access to otherwise inaccessible knowledge), quick learning (QL) (i.e., learning occurs either quickly or not at all), and innate ability (i.e., the ability to acquire knowledge is innate). Schommer-Aikins's (2004) studies indicate that multiple epistemic beliefs (i.e., CK and quick leaning) are related to an ill-defined story-completion task, differ by gender, and develop in a predictable sequence among adolescents.

Schommer-Aikins (2004) and Schommer-Aikins and Hutter (2002) conceptualized these five dimensions of epistemological belief 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 result, the three dimensions of "certainty of knowledge," "OA," and "SK" represent one's beliefs about the nature of knowledge. The two epistemic factors showing beliefs about knowledge acquisition are "innate ability" and "QL."

Moral Development

We derived the major developmental perspectives underlying our education program and study from the theoretical writings of Kohlberg (1975, 1981, 1984) and the modification of this theory by James Rest and the neo-Kohlbergians (Rest et al. 2000). Kohlberg (1975) asserted that moral reasoning developed and was articulated sequentially and hierarchically from childhood into adulthood. His findings show culturally universal stages of moral development rather than relative values, and reflect developmental aspects as opposed to the mere learning of rules and acquisition of 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. Individuals develop a capacity to deal with increased cognitive complexity and the abstraction required to comprehend the reasoning of each successive stage.

Rest agreed with Kohlberg's claim that qualitatively different forms of moral judgment can be identified and that development involves the growing use of more advanced or sophisticated reasoning. He disagreed, however, with Kohlberg's claim that development proceeds through a stepwise sequence of internally consistent stages. Rest 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. As a result, Rest refers to the development process as schemas (soft, more permeable stages) rather than hard stages, like Kohlberg (Rest et al. 2000). Moreover, he and his school, the neo-Kohlbergians, have insisted that cognitive moral reasoning does not alone predict actual moral behavior. Instead, the neo-Kohlbergians argue that moral sensitivity, moral motivation and moral character accompany moral judgment to produce actual behavioral outcomes (Rest 1994).

Class Design for Science Ethics Education

Our course was designed to promote students' epistemological beliefs and moral development, particularly their epistemological beliefs about and moral judgmental abilities regarding their fields of study: the natural sciences and engineering. To achieve this goal, we ensured that our education program included effective educational interventions that help students develop in four aspects suggested by Han and Jeong (2009) (see Fig. 1): their moral judgment to make a proper decision in situations that offer complicated dilemmas (Rest 1994), their moral sensitivity to detect implicit moral problems and imagine cause-and-effect chains (Rest et al. 1999), their epistemological beliefs that enable them to comprehend the sophisticated and socio-interactive nature of scientific knowledge and scientific works (Han 2006; Kuhn 1996; Latour 2005; Zeidler et al. 2005), and, finally, their ability to perform metacognition on the relationship between science and society to understand the sophisticated and complicated interactions between those two factors (Latour 2005; Jost et al. 1998; Swanson and Hill 1993).

To improve epistemological beliefs and moral judgment in these four aspects, our program featured four steps proposed by Han and Jeong (2009). First, we introduced various contemporary theories in STS from the fields of philosophy, history, sociology, and ethics of science and technology to our students. We expected such theories to provide students with a new opportunity for intellectual challenges. Such STS theories present a sophisticated view of the nature of science from a more

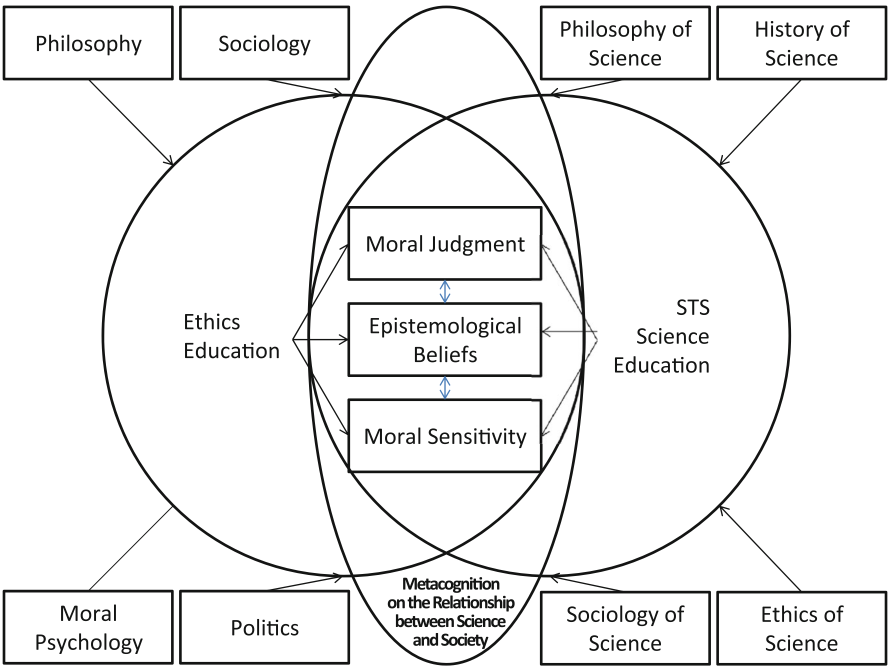

Fig. 1 Backgrounds and educational objectives of science ethics education

advanced perspective than students originally held. Such a perspective can arouse inner cognitive conflicts in students' reasoning, and produce inner motivations to internalize the sophisticated perspectives in the students, before promoting the development of both epistemological beliefs and moral judgment to a higher and sophisticated level (Lapsley 1996; Hofer and Pintrich 1997).

Second, we linked these STS theories to real-world scientific and technological problems. We introduced several dilemmas from the fields of natural science and engineering, and then applied previously introduced STS theories to each case. We expected this combination of real-world problems and STS theories to provide students with the opportunity to think about how they perceive the nature of scientific knowledge, the way of scientific works, and how they make decisions about socio-scientific dilemmas while also addressing real-world problems. Moreover, it was believed that this step would be particularly beneficial to students majoring in or planning to major in science and engineering. Because such cases are linked to students' research interests and expertise, they are better able to make sense of them, and they much more easily attract their attention (Ozaktas 2011).

Third, we provided the students with an opportunity to evaluate the STS theories and discuss social and ethical issues in the field of science and technology from an ethical perspective. The first two steps were theoretical and lecture-based. In this third step, however, students had the chance to evaluate the dominant theoretical perspectives of STS, think impacts of the social and ethical issues related to scientific and technological progress on society and our quality of life, and evaluate alternative solutions from the long term perspective of moral consequences and from the perspective of the ideal moral self (in other words, "Is that the person you want to be?") and the ideal moral world (in other words, "Is that a world you'd like to live in?"). We expected this activity-oriented step enabled the students to modify and develop their own perspectives and thinking processes.

Finally, students had time to reflect on their belief systems, what they learnt and how they changed over the course of the class. As Kirschenbaum (2000) pointed out, students benefit from contemplating and confirming newly formed moral beliefs and processes at the end of the class, thereby maximizing the effect of the educational intervention.

Using this basic structure, we designed a semester-long course for a group of Korean high school science students gifted in science and engineering. This single semester of 16 weeks was separated into two parts: first, the introduction and lectures; and, second, various activities including discussions and presentations. The first part lasted 7 weeks and offered an introduction to STS theories and how to reinterpret and critically evaluate real scientific and technological problems using a theoretical framework. This first part corresponds with the first two steps of our educational model—introduction to theory and the application of theory to real scientific problems. The contents of this first part are presented in Table 1.

Then, from 9 week to the end of the class, students were engaged in various student-oriented activities, including discussions and presentations that apply the theoretical frameworks they studied in the first part. This second part corresponds to the third and fourth steps of our educational model (Table 2).

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 reality. 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 Topics 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

In addition to these classes, students were given a mid-term examination in week 8. It consisted of both short-answer and essay problems to confirm whether or not each student fully understood STS theories and related issues. In addition, each was required to submit a reflection paper at the end of the course. Students also had to choose and present on one topic between weeks 9 and 15. Afterward, the other students questioned the presenter and offered feedback and criticism. All of the students had to write a reflection paper based on the criticisms of their peers. In it they were asked to think about their responses to the criticisms and questions of their peers, and how they might improve their knowledge and understanding of the topic. Final grades were assigned between A and F, based on mid-term scores, the student presentation, the final reflection paper and participation.

Method

Subject

Our semester-long class focusing on science ethics started in mid-February and ended in mid-June. High school science students gifted in science and engineering took the class as a major-elective subject for 2 h each week. There were thirteen male students and two female students. All of them were in the eleventh grade and majoring in science and engineering, including mathematics, physics, chemistry, bio science, earth science or computer science and engineering. They were selected as gifted students in the fields of natural sciences and technology when they first entered this high school. Outside of this class, they were usually also taking liberal arts courses—Korean, English, social studies, music, fine art, physical education, etc.—as well as classes in their majors—calculus, dynamics, organic chemistry, etc. In general, they were taking these classes up to 20 h per week.

Measurement

We measured students' epistemological beliefs and moral judgment levels using a qualitative method—semi-structured essay writing. Students were asked to complete an essay on 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: one on epistemological beliefs and another on moral judgment. In the first part, there were three questions, all of which were designed to measure the students' epistemological beliefs: SK, CK and innate learning (IA). The latter part consisted of two questions aimed at measuring students' moral judgmental abilities in both a scientific moral dilemma and in a general moral dilemma widely used for moral judgment measurement, the defining issues test (DIT), designed by the neo-Kohlbergians (Rest 1979). We had students complete this essay at the beginning of the semester (the pre-test) and at the end of the semester (the post test). The students' essays were one to two thousand words long in general (see the "Appendix" for essay questions).

In total, fifteen papers were submitted at both the beginning and end of the semester. Of those fifteen responses, however, one student's response was omitted, because he imprudently submitted the same paper at both the beginning and the end of the semester. The remaining fourteen responses were analyzed using a qualitative method. First, before coding each student's response, we segmented the initial essay responses. We extracted segments from our raw data: these were portions of each student's response that contained independent meanings in themselves. Each segment was a basic unit for our coding process and further analyses (Emerson et al. 2011). Then, for further statistical analyses, we coded each segment according to our own scheme. This process enabled us to conduct further quantitative analyses on the 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 theoretical model of epistemological beliefs proposed by Schommer-Aikins (2004). The overall structure and format of each question was drawn from the Epistemological Beliefs Inventory (EBI) developed by Bendixen et al. (1998), based on Schommer-Aikins's five components model. Each of the first three questions corresponds to SK, CK and IA in Schommer-Aikins's epistemological belief model. OA and QL were merged with the three questions. The first two questions, which deal 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 et al. (2008) suggest that two dimensions of the epistemological beliefs—SK and CK—concern the nature of knowledge, while the other two components, IA and QL, deal with the nature of knowing and knowledge acquisition. Moreover, according to their study, in the first component, the nature of knowledge can be divided into two smaller dimensions: simplicity versus complexity (SK) of knowledge, and certainty versus complexity (CK) of knowledge. OA is assimilated into the nature of these two components on the nature of knowledge. Our three questions, therefore, which cover the degree of the simplicity of knowledge, the degree of the certainty of knowledge, and the nature of knowledge acquisition, and measured the students' epistemological beliefs, based on the theoretical framework presented by Mason et al. (2008).

All three of these questions were designed to ask about the nature of scientific knowledge and the acquisition of scientific knowledge, because we intended to use these questions to measure the epistemological beliefs of students majoring in science and engineering. In particular, we wanted these questions to introduce important topics in the 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 the students' responses to these three questions. Zero 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 thinks that scientific knowledge is complicated and multifaceted (SK), uncertain and modifiable (CK), and scientific abilities are acquired through effort and practice (IA). Between 0 and 1, 0.5 means the student showed an intermediate level of epistemological belief development. A student score of each component was calculated by averaging all assigned numbers for the individual component. Calculated scores therefore ranged between 0 and 1.

When analyzing student responses to the two moral dilemmas, we used the coding method presented in Kohlberg's moral judgment interview (MJI). Although there is a quantitative measurement for moral development called DIT, subjects are not, however, able to generate open-ended 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 responses (Elm and Weber 1994), allowing us to investigate more deeply the nuances of the moral decision-making processes. According to the stage model of moral judgment development presented in Kohlberg (1981, 1984), we assigned corresponding levels (1–5) of moral judgment to each segment. We used the basic idea for MJI coding methodology established by Colby and Kohlberg (1987). Though we designed the first three questions to measure epistemological beliefs, the fourth question was directly related to a scientific and technological moral dilemma. This question was intended to deal with various ethical issues in the fields 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). Finally, the last question, which was designed to measure students' moral judgment development in general, was extracted from a traditional Kohlbergian moral judgment measurement—MJI and DIT.

All of these questions were designed to appropriately measure the students' developmental levels in moral judgment. Because the prototype of these questions, MJI and DIT, was designed to measure subject's moral judgments in complex social contexts, forcing subjects to make a behavioral decision between conflicting values (Rest et al. 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 of the assigned level numbers in the student's responses to a particular question. Calculated levels thus ranged between 1 and 5.

Results

We first conducted a mixed model analysis to discern the overall effect of our STS program on students' epistemological beliefs and moral judgmental abilities. We set the participant as a random effect, and the pre- and post test conditions as fixed effects. The students' epistemological beliefs and moral judgment scores were the dependent variables.

$$\begin{aligned} y_{ijk} &= \mu_{ij} + \mathrm{e}_{\mathrm{ijk}} \\ &= \mu + A_i + B_j + \mathrm{e}_{\mathrm{ijk}} \end{aligned}$$

In this model, $\mathrm{y}_{\mathrm{ijk}}$ 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 ith 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.

Table 3 shows the descriptive statistics of the surveyed and segmented data that is used for mixed model analysis.

The mixed model analysis shows that there were significant developments in all psychological dimensions (SK, CK, IA, scientific and general moral judgment) between the pre- and post-tests. The intercepts of fixed effect (the pre- and post-test factor) in all dimensions were statistically significant at $p < .005$. We can therefore conclude that our STS-based ethics education program induced significant developments in students' epistemological beliefs and moral judgmental abilities at the whole-class level. The results of the mixed model analysis are presented in Table 4.

Following this analysis, we conducted a mixed model ANOVA to discover fully the differences between our students' pre- and post-test scores based on the previous mixed model. The results of the ANOVA show that there were significant differences between pre- and post-test scores in all measurements, SK ($F(1,13) = 21.03$, $p < .0001$) CK ($F(1,13) = 15.86$, $p < .0005$), IA ($F(1,13) = 21.11$, $p < .0001$), scientific moral dilemma ($F(1,13) = 23.31$, $p < .0001$) and the general Kohlbergian moral dilemma ($F(1,13) = 13.54$, $p < .001$) (see Figs. 2, 3).

Afterward, each student's individual pre-test and post-test scores were compared to each other using a t test. The results of the comparisons between pre-test and post-test epistemological belief components are presented in Table 5. First, in the dimension of SK, four students showed statistically significant increases of 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 ($t(6) = 4.9$, $p < .005$). Students 4, 5, 6, 7, 11, 12 and 14 showed marginal increases, and 10 and 13 showed marginal decreases, but none of those changes was statistically significant. Second, in the dimension of CK, two students showed statistically

Table 3 Descriptive statistics of the surveyed data

	Epistemological beliefs			Moral judgment	
	SK	CK	IA	Scientific	General
Number of participants	14	14	14	14	14
Number of total response segments	92	85	84	65	66
Segments per participant					
(Minimum)	4	4	4	3	2
(Average)	6.6	6.1	6	4.6	4.7
Mmaximum)	9	10	10	6	6
Mean score of whole segments					
(Pre-test)	0.50	0.66	0.58	3.64	3.59
(Post-test)	0.80	0.90	0.90	4.52	4.06

Table 4 Mixed effect analyses on the development of epistemological beliefs and moral judgment

	Epistemological beliefs						Moral judgment			
	SK		CK		IA		Scientific		General	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Effect										
Fixed effect										
Intercept (Pre)	0.504****	0.063	0.683****	0.069	0.588****	0.067	0.816****	0.160	0.452****	0.122
Slope (Post–Pre)	0.293****	0.066	0.221****	0.054	0.317****	0.061	3.666****	0.147	3.604****	0.176
Random effect										
Participant	0.178	0.049	0.213	0.050	0.144	0.049	0.381	0.116	0.570	0.131

* $p < .1$, ** $p < .05$, *** $p < .01$, **** $p < .005$. $N = 14$

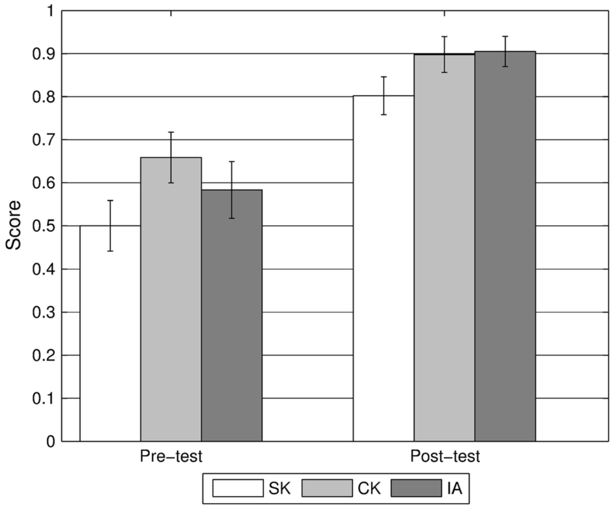

Fig. 2 Changes in students' epistemological beliefs

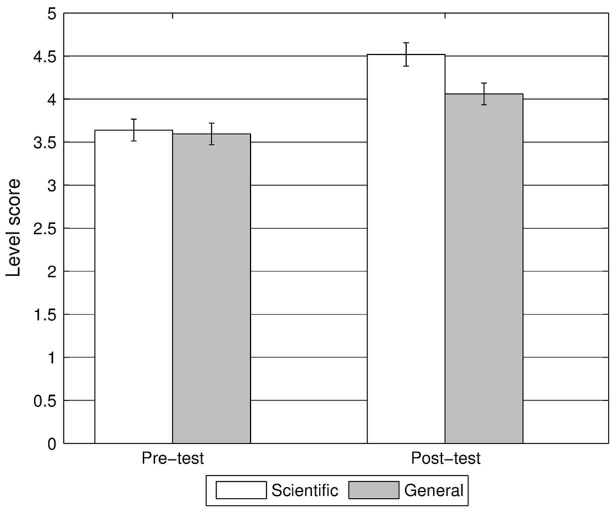

Fig. 3 Changes in students' moral judgment levels

significant increases of 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 ($t(5) = 5.92, p < .005$). Students 7, 8, 9, 10 and 14 showed marginal increases, and 5 showed a marginal decrease, but none of those changes was statistically significant. However, because the standard deviation values of both the pre-test and post-test CK scores were zero for student 6, we were not able to conduct a t test for this case. Finally, in the dimension of IA, four students showed statistically significant increases of 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 ($t(2) = 3, p < .1$). Students 4 and 8 showed marginal increases, and 7 showed a marginal decrease, but none of those changes was statistically significant. Unfortunately, because the standard deviation values of both the pre-test and post-test IA scores was zero for students 6, 11 and 13, we were unable to conduct a t test for them.

Table 6 shows the results of the t tests between pre-test and post-test moral judgment levels according to the Kohlbergian stage model. First, for the scientific moral dilemma (M1), four students showed statistically significant increases of 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 ($t(2) = 3$, $p < .1$). Students 3, 4, 7, 8, 9, 12 and 14 showed marginal increases, and 5 showed marginal decreases, but none of these was statistically significant. However, because the standard deviation values of both pre-test and post-test M1 scores were zero for students 1 and 2, we were unable to conduct a t test for them. Moreover, for the general Kohlbergian moral dilemma (M2), two students showed statistically significant increases of at least $p < .1$ at two-tailed t tests, six students showed marginal increases, and no students showed a marginal decrease. Students who showed statistically significant increases in M2 were 7 ($t(3) = 3.87, p < .05$) and 13 ($t(2) = 3, p < .1$). Students 4, 5, 6, 9, 11 and 12 showed marginal increases, but none of those changes was statistically significant.

Table 5 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

* $p < .1$, ** $p < .05$, *** $p < .01$, **** $p < .005$

Table 6 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

* $p < .1$, ** $p < .05$, *** $p < .01$, **** $p < .005$

Here are some examples of students' responses. These excerpts were extracted from the responses of students who showed the most significant development in each dimension. These should help readers understand how actual developmental changes in students occurred over the course of the semester. First, in the dimension of SK, student 9 showed the most rapid developmental change. Before the beginning of the semester, he demonstrated a simplistic understanding of scientific knowledge and processes. He wrote:

> Natural sciences are a systematic knowledge of universal truths and laws. Although there might be some complexities, because natural sciences do not contain any logical fallacies, we can simply and clearly explain natural phenomena. [Pre-survey, Student 9, 24 February 2011].

However, by the end of the semester, he responded as follows:

> I do not think natural sciences can explain everything simply and clearly. The natural sciences aim to simplify and systemize complicated natural phenomena. Although we have successfully explained many phenomena, there are many things that have not yet been explained. […] I am not sure whether scientific explanations are simple and clear. [Post-survey, Student 9, 15 June 2011].

In comparison with his responses from the beginning of the semester, he seems to have developed a more sophisticated and constructivistic belief in the domain of SK. He now understand that the knowledge produced by and the processes used in the field of natural sciences cannot be simply defined and explained.

In the domain of CK, student 3 showed the most significant increase in his score. At the beginning of the semester, when we attempted to measure the degree of his CK belief, he responded as follows:

> The natural sciences can bring us certain and unchanging truths. […] Although there might be some mistakes and errors in scientific fields, the role of the sciences is to fix those problems, and to certify our explanations for natural phenomena. By repeating this process, the natural sciences will bring us certain and eternal truths. [Pre-survey, Student 3, 23 February 2011].

Just as student 9 did in the domain of SK, student 3 also demonstrated a more sophisticated and developed belief in the domain of CK:

> The natural sciences cannot immediately provide solutions for problems. […] The natural sciences do not always produce correct answers. Likewise, some scientific knowledge that was regarded as truth can be modified and changed. For instance, in the field of particle physics and cosmology, researchers cannot provide us with certain and correct answers. [Post-survey, Student 3, 16 June 2011].

By the end of the semester, student 3 had come to believe that scientific knowledge is not always certain, and that it can be modified and changed.

In the domain of IA, student 9 showed the most rapid developmental change. In his pre-test survey, he responded that the great discoveries in the natural sciences had been done by the scientists who were originally gifted and talented.

> Without natural talent, a person cannot become a great scientist. […] And without a genius's intuition, a scientist cannot discover a new fact. I heard some stories about a scientist who did not discover anything, even though he spent a couple of decades working. Hence, a great scientist must have natural talent. [Pre-survey, Student 9, 24 February 2011].

By the end of our class, he was able to understand effort was essential to making advances in the natural sciences, and that natural talent alone is insufficient.

> I think that even ordinary people can develop their insights by establishing, by watching and by considering things around them repeatedly. Thus, a person can become a great scientist by endless learning and effort. [Post-survey, Student 9, 15 June 2011].

As we can see, the student came to perceive that the abilities for scientific works can be developed through education and effort. This student was able to develop more constructivistic beliefs about scientists' abilities.

In the domain of scientific moral judgment, student 11 showed the most significant development throughout the semester. At the beginning of the course, he made moral decisions based on the considerations on his social relations, norms and laws; this decision-making pattern corresponds to the third to fourth stages (the conventional level) of the Kohlbergian moral developmental model.

> We should continue our research. If we stop studying at that point, the money funded by citizens' taxation will be totally wasted. Moreover, scientists will lose their jobs, and they will be very sad and fall into despair. Also we will be able to reap huge benefits by developing medical science. [Pre-survey, Student 11, 19 February 2011].

However, by the end of the semester, he had started to consider much wider aspects of a given situation, and more universal principles, rather than social norms and laws, which can be limited to a specific society or country. This viewpoint corresponds to the fifth stage (the post-conventional level) of the Kohlbergian model.

> The ultimate goal in developing this medicine is to enhance the quality of human life. However, if the material that we are developing will cause environmental problems, then it will also cause severe problems. We will forget the ultimate goal of our study—improving the quality of life—if we destroy our environment. [...] It will threaten other animals and plants' lives. Hence, we should stop a study that may cause severe environmental problems, and develop an alternative approach. [Post-survey, Student 11, 15 June 2011].

Finally, in the domain of general moral judgment, student 7 showed the greatest increase. In his pre-test, the student's responses corresponded to the third stage of the Kohlbergian model; he mainly considered social relations and evaluations in solving the presented moral dilemma.

> He greatly contributed to the society for eight years. If he stayed in prison during that period, he was not able to contribute to the society and the economy. Given the potential benefits and contributions of his company to the society, it would be better not to arrest him. [Pre-survey, Student 7, 20 February 2011].

However, at the end of the class, he attempted to use post-conventional perspectives when he was solving a moral dilemma; the student considered the value of conscience above social norms and laws. Moreover, he partially utilized stage four (the conventional level, social norm and laws) when making his moral decisions.

> The victim (and his family) would want him to be arrested. [...] I think that if he leaves prison at the expiration of his term, he will be able to take a load off his mind—the pang of conscience. Finally, he will be able to enjoy a better life after spending a couple of years in prison. [Post-survey, Student 7, 15 June 2011].

Given those segments extracted from the results of this survey, our qualitative data shows that our students' epistemological beliefs and moral judgment were developed during the semester. The qualitative data is in line with and supports the results of our statistical analyses of the students' development.

Discussion

There were statistically significant developments in both the students' epistemological beliefs and their moral judgment. In the dimension of epistemological beliefs, STS theories that challenged students' previous perspectives on scientific knowledge and scientific work might have promoted the students' development. The philosophy of science deals with the nature of scientific knowledge and "ways of knowing" in science (Bird 1998); the history of science concerns the complicated, non-linear process of the development of science, and shows us actual scientific processes throughout the historical record (Darrigol 2007); while the 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 activities that require individuals to reflect upon previous beliefs (Brownlee et al. 2001), that use high-order thinking activities in educational experiences (Schommer-Aikins and Hutter 2002), that offer chances to think about the social construction of knowledge (Baxter Magolda 2004), and that give opportunities to talk about complicated and ill-structured problems regarding the nature of knowledge (Hofer 2001) foster the development of epistemological beliefs toward more constructivist perspectives. Also, an earlier empirical study done by Han (2006) indicates that intensive engagement with STS classes induces a statistically significant development in some aspects of epistemological beliefs, specifically CK, in college students. As a result, we can say that lectures and student-oriented activities that deal with STS theory should challenge students' previous perspectives and provide them with a more sophisticated view of science.

In addition, this study contributes to the development of a novel method to measure the effects of a science ethics education program. An earlier empirical study conducted by Blatt and Kohlberg (1975) showed that vigorous moral-dilemma discussion can help students' develop higher-level moral judgment. Indeed, in the field of professional ethics education, various studies have shown significant moral development in students following ethics educational interventions. A nursing ethics education program promoted significant development in students' moral judgment and actual clinical practice (Duckett and Ryden 1994); dental ethics educational interventions resulted in the significant development of dental students' both moral sensitivity and judgment (Bebeau 1994); and intentionally designed ethics education programs significantly increased the moral judgment scores of medical and veterinary students (Self and Baldwin 1994; Self et al. 1994). Moreover, an ethics education program for students majoring in science and engineering that includes topics related to the responsible conduct of research (RCR) significantly developed students' perspective-taking, moral efficacy and moral courage (May and Luth 2012). All of these programs were designed to fit the special interests of their students; each program used potential moral dilemmas in the students' own fields as class materials. Indeed, an earlier study showed that STS-applied courses were more effective than general ethics and philosophy courses to promote the moral development of science and engineering (Han 2006), because such STS materials focused on the kinds of moral situations that reflected students' research interests and daily experiences better than general "pure" humanities, such as general moral philosophy and history (Ozaktas 2011). These findings are potentially supported by resent neuroscientific studies of the relationship between cultural norms and one's own self-conception. Even though self-conception in the human brain is influenced by cultural and environmental factors—which may include education—actual self-conception development in the human brain can occur when a person willfully, voluntarily and actively engages such factors (Kitayama and Tompson 2010). Neuroimaging studies have also shown that self-referring activities, which are closely related to subjects' context of life, are significantly more associated with prefrontal executive, memory encoding and recalling processes than other kinds of activities (Craik et al. 1999; Kelley et al. 2002; Johnson et al. 2002; Zhu et al. 2007). As a result, STS materials directly related to the interests of the 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 education programs induced spontaneous discussion among students, and encouraged students to pursue their moral development through inner moral conflicts and reflections. This coincides with the main objective and discovery of Blatt and Kohlberg's (1975) study: effective moral education promotes moral development.

As a result, this study provides some possible paths for future research. First, this study contributes to the formulation of an ethics education program for science and engineering students. Because we used STS theories and topics that directly dealt with real scientific and technological issues in our curriculum, our program is more attractive than traditional philosophical or ethics classes for science and engineering students. This could, in fact, be the reason why our program led to significant and meaningful developments in students. Second, the essay-based qualitative measurements that we used in our study could lead to further studies that attempt to measure the effects of science and engineering ethics education programs. We attempted to measure the effects of a "science and engineering" ethics education program that focused on science and engineering topics, rather than general moral and philosophical issues. Earlier measurements that sought to measure the more general domain of epistemological beliefs and moral judgment would be unable to properly discover changes in epistemic and moral development in scientific and technological domains. However, because our essay questions were developed to fit into the contexts and lives of science and engineering students, they were particularly useful in measuring the effects of our ethics education program in the fields of science and engineering. Even though we did not design a quantitative measurement that could be applied to large-group studies, our essay questions could be useful candidates for questions in a quantitative measurement in future studies.

Nonetheless, this study has a few limitations. First, our study used not a true-experimental design, but a quasi-experimental design: one group of pre- and post-test comparisons. As a result, we cannot be sure whether the detected changes in our students were wholly the product of our education program, or whether other factors, such as history and maturation, provided the causal link (Campbell and Stanley 1963). However, we may suppose that STS-related ethics education programs are significantly more effective at promoting students' development in epistemological beliefs and moral judgment by considering earlier studies. For instance, Han (2006) showed that only students who took multiple STS-related classes showed significant development in both psychological dimensions, particularly among students who were majoring in the natural sciences or engineering (Han 2006). Zeidler et al. (2009) showed that a well-designed science ethics education program using socioscientific issues induced a significant development in students' reflective judgment; students in the control group did not show significant development. In addition, Tsai (1999) proved that STS-applied instruction promoted significant development in a group of Taiwanese female high school students' epistemological beliefs, unlike traditional science education program.

Moreover, because the size of our class was proportionally small ($N = 14$), our sample size could have negatively affected the reliability of the sample and our generalizations (Gould 2002), while limiting the power of our statistical analyses (Cohen 1992). Indeed, we were unable to recruit a large group of students for 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 in Korea (as selected by the ministry of education in Korea). As a result, the number of students in our class was limited, and it was difficult to recruit additional students outside 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 a much larger group. However, to increase the generalizability of our study, it would be useful to invent a quantitative measurement based on our essay questions, and apply it to a much larger group in future studies. These points should be further considered and analyzed in future studies on the effects of an STS-based science ethics education program.

Conclusion

In the present study, we developed a new STS-based science ethics education program for high school science students. Unlike earlier, more traditional moral-philosophical classes, we attempted to introduce various STS theories from the fields of philosophy, history, sociology and the ethics of science and technology that aligned with the students' interests and daily lives. We expected that these materials would significantly challenge students' existing beliefs about scientific knowledge and scientific work, and cause inner conflicts forcing students to develop more sophisticated beliefs about the nature of science and scientific work. In addition, because developed constructivist epistemological beliefs are closely associated with sophisticated post-conventional moral judgment competence, a meaningful development in students' moral judgment was also expected. We applied this STS-based curriculum for a semester to a group of Korean high school students gifted in science and engineering. All of these students submitted intensive essays about their epistemological beliefs and moral judgment about scientific and technological issues for a pre- and post-test. The results showed that there were statistically significant developments in students' both epistemological beliefs and moral judgment competence.

Finally, our study used an essay-based qualitative measurement to study the effects of our education program. Our study contributed to the development of science students' beliefs about the sciences and their moral judgment competence on scientific issues. Moreover, because our essay-based measurement focused particularly on scientific and technological issues rather than on general moral-philosophical dilemmas that have been used in traditional measurements, our method might provide a model for further studies on the development of science and engineering ethics education programs. Although we had significant results and our study contributes to a growing body of knowledge, it also contained some limitations. Due to its small sample size and quasi-experimental design, the generalizability and reliability of our results are limited. As a result, future studies should improve upon our research design, develop a new quantitative measurement based on our essay measurements, and apply this new design and measurement to a much larger group to correct the limitations of our study.

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 words, do you think science can explain natural phenomena to us 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, do 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 3 years ago; we got one million dollars per year from the national foundation. We are on the last phase of our 5 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 an 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 1 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 1 day, Mrs. Jones, an old 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?

References

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Baxter Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist, 39*(1), 31–42.

Bebeau, M. J. (1994). Influencing the moral dimensions of dental practice. In J. R. Rest & D. Narvaez (Eds.), *Moral development in the professions: Psychology and applied ethics* (pp. 121–146). Hillsdale, NJ: Lawrence Erlbaum Associates.

Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self voice and mind*. New York, NY: Basic Books.

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87*(3), 352–377.

Bendixen, L. D., Schraw, G., & Dunkle, M. E. (1998). Epistemic beliefs and moral reasoning. *The Journal of Psychology, 132*, 187–200.

Bird, A. (1998). *Philosophy of science*. London: UCL Press.

Blatt, M., & Kohlberg, L. (1975). The effect of classroom moral discussion upon children's level of moral judgment. *Journal of Moral Education, 4*, 129–161.

Brownlee, J., Purdie, N., & Boulton-Lewis, G. (2001). Changing epistemological beliefs in pre-service teacher education students. *Teaching in Higher Education, 6*(2), 247–268.

Campbell, D. T., & Stanley, J. C. (1963). *Experiment and quasi-experimental designs for research*. Dallas, TX: Wadsworth Publishing.

Cohen, J. (1992). A Power primer. *Quantitative Methods in Psychology, 112*(1), 155–159.

Colby, A., & Kohlberg, L. (1987). *The measurement of moral judgment*. Cambridge: Cambridge University Press.

Colby, A., Kohlberg, L., Gibbs, J., Lieberman, M., Fischer, K., & Saltzstein, H. D. (1983). A longitudinal study of moral judgment. *Monographs of the Society for Research in Child Development, 48*, 1–124.

Craik, F. I. M., Moroz, T. M., Moscovitch, M., Stuss, D. T., Winocur, G., Tulving, E., et al. (1999). In search of the self: A positron emission tomography study. *Psychological Science, 10*(26), 26–34.

Darrigol, O. (2007). For a history of knowledge. In K. Gavroglu & J. Renn (Eds.), *Positioning the history of science* (pp. 33–34). Dordrecht: Springer.

Davis, G. A., & Rimm, S. B. (2004). *Education of the gifted and talented* (5th ed.). Boston, MA: Pearson Education Inc.

Doorn, N., & Kroesen, J. O. (2011). Using and developing role plays in teaching aimed at preparing for social responsibility. *Science and Engineering Ethics.* doi:10.1007/s11948-011-9335-6.

Duckett, L. J., & Ryden, M. B. (1994). Education for ethical nursing practice. In J. R. Rest & D. Narvaez (Eds.), *Moral development in the professions: Psychology and applied ethics* (pp. 51–69). Hillsdale, NJ: Lawrence Erlbaum Associates.

Elm, D. R., & Weber, J. (1994). Measuring moral judgment: The moral judgment interview or the defining issues test? *Journal of Business Ethics, 13*(5), 341–355.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (2011). *Writing ethnographic field notes* (2nd ed.). Chicago, IL: The University of Chicago Press.
Gould, J. E. (2002). *Concise handbook of experimental methods for the behavioral and biological sciences*. Boca Raton, FL: CRC Press LLC.
Greene, J. A., Torney-Purta, J., & Azevedo, R. (2010). Empirical evidence regarding relations among a model of epistemic and ontological cognition, academic performance, and educational level. *Journal of Educational Psychology, 102*(1), 234–255.
Grinnell, F. (2012). Research integrity and everyday practice of science. *Science and Engineering Ethics*. doi:10.1007/s11948-012-9376-5.
Han, H. (2006). A survey of effects of STS education on the university students' moral development and epistemological beliefs: Using DIT and EBI. *Journal of Ethics Education Studies, 9*, 201–218.
Han, H., & Jeong, W. (2009). Using STS theories and issues for moral education. *Journal of Moral & Ethics Education, 29*, 367–386.
Herkert, J. R. (2001). Future directions in engineering ethics research: Microethics, macroethics and the role of professional societies. *Science and Engineering Ethics, 7*, 403–414.
Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Journal of Educational Psychology Review, 13*(4), 353–383.
Hofer, B. K. (2006). Beliefs about knowledge and knowing: Integrating domain specificity and domain generality: A response to Muis, Bendixen, and Haerle (2006). *Educational Psychology Review, 18*, 67–76.
Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*, 88–140.
Jeong, C. (2003). *A cross-cultural study of the relationships between epistemological beliefs and moral judgment as a psychological foundation for moral education*. (Unpublished doctoral dissertation). Athens: University of Georgia.
Johnson, S. C., Baxter, L. C., Wilder, L. S., Piper, J. G., Heiserman, J. E., & Prigatano, G. P. (2002). Neural correlates of self-reflection. *Brain, 125*, 1808–1814.
Jost, J. T., Kruglanski, A. W., & Nelson, T. O. (1998). Social metacognition: An expansionist review. *Personality and Social Psychology Review, 2*(2), 137–154.
Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S., & Heatherton, T. F. (2002). Finding the Self? An Event-Related fMRI Study. *Journal of Cognitive Neuroscience, 14*(5), 785–794.
King, P., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.
Kirschenbaum, H. (2000). From values clarification to character education: A personal journey. *Journal of Humanistic Counseling, Education & Development, 39*(1), 4–20.
Kitayama, S., & Tompson, S. (2010). Envisioning the future of cultural neuroscience. *Asian Journal of Social Psychology, 13*, 92–101.
Klaczynsk, P. A. (2000). Motivated scientific reasoning biases, epistemological beliefs, and theory polarization: A two-process approach to adolescent cognition. *Child Development, 71*(5), 1347–1366.
Kohlberg, L. (1975). Continuities and discontinuities in childhood and adult moral development revisited. In B. Baltes & W. Schaie (Eds.), *Life-span developmental psychology: Research and theory* (pp. 179–204). New York, NY: Academic Press.
Kohlberg, L. (1981). *The philosophy of moral development: Moral stages and the idea of justice*. San Francisco, CA: Harper & Row.
Kohlberg, L. (1984). *The psychology of moral development: The nature and validity of moral stages*. San Francisco, CA: Harper & Row.
Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*, 319–337.
Kuhn, T. S. (1996). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.
Lapsley, D. K. (1996). *Moral psychology*. Boulder, CO: Westview Press.
Latour, B. (2005). *The pasteurization of France*. Cambridge, MA: Harvard University Press.
Logino, H. (2011). The social dimensions of scientific knowledge. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy*. Retrieved Sept 11, 2012, from http://plato.stanford.edu/archives/spr2011/entries/scientific-knowledge-social/.
Mason, L., Gava, M., & Boldrin, A. (2008). On warm conceptual change: The interplay of text, epistemological beliefs, and topic interest. *Journal of Educational Psychology, 100*(2), 291–309.

May, D. R., & Luth, M. T. (2012). The effectiveness of ethics education: A quasi-experimental field study. *Science and Engineering Ethics*. doi:10.1007/s11948-011-9349-0.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain generality and domain specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18*, 3–54.

Ozaktas, H. M. (2011). Teaching science, technology, and society to engineering students: A sixteen year journey. *Science and Engineering Ethics*. doi:10.1007/s11948-011-9329-4.

Perry, W. G. (1970). *Forms of intellectual and ethical development in college years*. New York: Academic Press.

Rest, J. R. (1979). *Development in judging moral issues*. Minneapolis, MN: The University of Minnesota Press.

Rest, J. R. (1994). Background: Theory and research. In J. R. Rest & D. Narvaez (Eds.), *Moral development in the professions: Psychology and applied ethics* (pp. 1–26). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rest, J. R., Deemer, D., Barnett, R., Spickelmier, J., & Volker, J. (1986). Life experiences and developmental pathways. In J. R. Rest (Ed.), *Moral development: Advances in research and theory* (pp. 28–58). New York, NY: Praeger.

Rest, J. R., Narvaez, D., Bebeau, M. J., & Thoma, S. J. (1999). *Postconventional moral thinking: A neo-Kohlbergian approach*. Mahwah, NJ: Erlbaum.

Rest, J. R., Narvaez, D., Thoma, S. J., & Bebeau, M. J. (2000). A neo-Kohlbergian approach to morality research. *Journal of Moral Education, 29*, 381–395.

Rich, J., & DeVittis, J. (1994). *Theories of moral development* (2nd ed.). Springfield, IL: Charles C. Thomas Publishers.

Schommer-Aikins, M. (2004). Explaining the epistemological belief system: Introducing the embedded systemic model and coordinated research approach. *Educational Psychologist, 39*, 19–29.

Schommer-Aikins, M., & Hutter, R. (2002). Epistemological beliefs and thinking about everyday controversial issues. *The Journal of Psychology, 136*, 5–20.

Scott, D., & Morrison, M. (2006). *Key ideas in educational research*. London, UK: Continuum.

Self, D. J., & Baldwin, D. C., Jr. (1994). Moral reasoning in medicine. In J. R. Rest & D. Narvaez (Eds.), *Moral development in the professions: Psychology and applied ethics* (pp. 147–162). Hillsdale, NJ: Lawrence Erlbaum Associates.

Self, D. J., Olivarez, M., & Baldwin, D. C., Jr. (1994). Moral reasoning in veterinary medicine. In J. R. Rest & D. Narvaez (Eds.), *Moral development in the professions: Psychology and applied ethics* (pp. 163–171). Hillsdale, NJ: Lawrence Erlbaum Associates.

Sprigge, T. L. S. (1964). Definition of a moral judgment. *Philosophy, 39*(15), 301–322.

Swanson, H. L., & Hill, G. (1993). Meta cognitive aspects of moral reasoning and behavior. *Adolescence, 28*(111), 711–735.

Tsai, C. (1999). The progression toward constructivist epistemological views of science: A case study of the STS instruction of Taiwanese high school female students. *International Journal of Science Education, 21*(11), 1201–1222.

Walker, L. J. (1988). The development of moral reasoning. *Annals of Child Development, 5*, 33–78.

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research in Science Teaching, 46*(1), 74–101.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357–377.

Zhu, Y., Zhang, L., Fan, J., & Han, S. (2007). Neural basis of cultural influence on self-representation. *NeuroImage, 34*, 1310–1316.