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ABSTRACT

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Tangled Up in Views: Beliefs in the Nature of Science and Responses to Socio-Scientific Dilemmas

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Tangled Up in Views: Beliefs in the Nature of Science and Responses to Socio-Scientific Dilemmas

The purpose of this study was to investigate the relationships between students' conceptions of the nature of science and their reactions to evidence that challenged their beliefs about socio-scientific issues. This study used 248 students from 9th and 10th grade general science classes, 11th and 12th grade honors biology, honors science, and physics classes, and senior level college preservice science education classes. Students responded to questions aimed at revealing their epistemological views of the nature of science and their belief convictions on selected socio-scientific issues. A smaller sub-set of students was selected based on varying degrees of belief convictions about the socio-scientific issues and selected students paired to discuss their reasoning related to those issues while being exposed to anomalous data and information from each other and in response to epistemological probes of an interviewer. A qualitative design that entailed the derivation of taxonomic categories through discourse analysis utilizing samples of fallacious reasoning, conceptions of science, and sample performances of thought as a result of dialogic interaction was utilized. Additionally, appropriate nonparametric tests were performed to examine whether paired discourse resulted in changing belief convictions. By engaging students in discourse on socio-scientific issues, this study was aimed at elucidating how students inherently utilize aspects of the nature of science through dialogic reasoning on moral and ethical issues. Taxonomic categories and samples of thought are presented and discussed, and implications for science education are addressed.

Tangled Up in Views: Beliefs in the Nature of Science and Responses to Socio-Scientific Dilemmas

INTRODUCTION AND PURPOSE

Current research findings on the nature of science (NOS) have suggested that science teachers should explicitly guide students in developing a proper understanding of the nature of the scientific enterprise (Abd-El-Khalick & Lederman, 1998; Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F., 1998). Other recent research has stressed the importance of students' argumentation and discourse as they ponder evidence, apply critical thinking skills, and formulate positions of various socio-scientific issues (Zeidler, 1997). The importance of the latter research is the fact that students' treatment of counter-evidence (anomalous data) follows varied psychological responses that reflect elements of scientific theory development (Chinn & Brewer, 1998; Chinn & Brewer, 1993).

If teachers support the notion that scientific literacy entails, at least in part, the ability of students to engage in active dialogue as they ponder evidence, apply critical thinking skills, and formulate positions on various topics, then informal discussions and formal debates that challenge students to use multiple views and competing evidence in rendering decisions becomes central to a broader view of scientific literacy that explicitly includes aspects of the nature of science. In addition, dialogic reasoning and argumentation has been found to challenge the core beliefs of students (Kuhn, 1991; Kuhn, 1992; Zeidler, 1997). By engaging students in discourse on socio-scientific issues this study serves to elucidating how students inherently involve aspects of the nature of science through dialogic reasoning.

By using scenarios that evoke moral and ethical considerations connected to real-world issues, explicit connections to the nature of science may become more apparent to the student. With these overriding themes in mind, this exploratory investigation examines the relationships between students' conceptions related to the nature of science and their reactions to evidence that challenges their beliefs about socio-scientific issues.

RESEARCH QUESTIONS AND CORRESPONDING RATIONALE

R1. In what ways do students' views of the nature of science influence their reactions to socio-scientific issues when confronted with information that challenges their initial beliefs?

Rationale: The development of an "adequate understanding of the nature of science" or an understanding of "science as a way of knowing" continues to be convincingly advocated as a desired outcome of science instruction (American Association for the Advancement of Science, 1989; Hazen & Trefil, 1991). Although the "nature of science" has been defined in numerous ways, it most commonly refers to the values and assumptions inherent to the development of scientific knowledge (Lederman & Zeidler, 1987). As much as we'd like to believe that science is truly an objective enterprise, it would be quite naive to assume that scientific endeavors are not molded and guided by social preconceptions and biased modes of thinking (Gould, 1995). Unfortunately, the delivery of science instruction in most classrooms today still relies heavily upon textbooks that give the impression that scientific knowledge has evolved in a linear and comprehensive manner. This, of course, is far from the reality of scientific progress. A larger and more important goal then of the explicit teaching of the nature of science in the classroom should therefore be to illuminate this misperception. By engaging students in scientific discourse activities that bring to light the tentative and social nature of science, a more comprehensive representation of the nature of science may be explored. This approached by presenting students with anomalous scientific data that challenges their core beliefs (Chinn & Brewer, 1998; Chinn & Brewer, 1993) or by engaging them in discussions on socio-scientific topics where students can challenge one another's beliefs.

R2. In what ways do students utilize evidence that conflicts with their initial core beliefs about socio-scientific problems?

Rationale: Research in this area has suggested that the characteristics of students' reasoning with moral issues in a socio-scientific context may not dramatically differ from reasoning when faced with anomalies on scientific issues (Zeidler, 1997). In both situations, the students' responses, when confronted with information that challenges their initial beliefs, can be categorized into a framework that reflects varied psychological responses of scientific theory development.

R3. How do an individual's belief convictions change when confronted with discrepant evidence?

Rationale: A study by Lord, Ross, & Lepper (1979) illustrates how subjects consistently evaluated "studies" of the effectiveness of capital punishment as a deterrent in a manner that favored their initial beliefs. Studies that were consistent with initial beliefs were found to be more convincing for the subjects, whereas studies that were counter to their initial beliefs were found to contain more flaws. Baron & Brown (1991) describe this propensity as "belief persistence" and provide numerous examples from psychology of how prior beliefs compromise our ability to evaluate counter evidence and criticism. This phenomenon gave Gould (1995) confidence to state that he would "reject any claim that personal preference, the root of aesthetic judgment, does not play a key role in science" (p. 93). Social implications in the development of scientific knowledge are just one aspect of the nature of science that needs to be explicitly taught to the students. In order to explore the reconciliation of personal beliefs, this study addresses the relationship between the students' level of conviction to their initial beliefs and their willingness to change beliefs once challenged.

R4. (a) To what extent is fallacious reasoning a mediating factor in the students' dialogic reasoning when confronted with viewpoints contrary to their initial core beliefs about socio-scientific issues? (b) If informal fallacies are found, what is the nature of their reasoning?

Rationale: Research has shown that when students are confronted with issues that challenge their initial core beliefs, they sometimes inadvertently and unknowingly change or modify the premises of an initial problem or argument.

This can occur when students introduce pragmatic inferences into a problem and confuse hypothetical matters with the original premises of the problem when reasoning about specific moral issues (Zeidler, 1997; Zeidler, Lederman, & Taylor, 1992). Since this study was designed to gain a further understanding of how students respond and argue their beliefs on socio-scientific issues, it was important to delineate valid dialogic reasoning from fallacious argumentation. Research has also indicated that as students construct their knowledge through personal experience when responding to anomalous data, their response will ultimately fall within one of the following conceptual categories: ignoring, rejecting, uncertainty, excluding, abeyance, reinterpreting, peripheral change, and theory change (Chinn & Brewer, 1998; Chinn & Brewer, 1993). If elements of fallacious argumentation can be characterized, teachers may be able to detect and guide students in the course of dialogue and valid argumentation.

SIGNIFICANCE OF THE STUDY

Theoretical Implications

This study examines the contextual links between students' understanding of the nature of science and the social enterprise of science via socio-scientific issues. More specifically, the tacit beliefs that students hold about scientific research and how those beliefs interact with the nature of a problem that entailed moral, ethical, and social considerations was investigated. The finding of this inquiry also add to our understanding of how students reconcile personal beliefs with discrepant evidence and anomalous data as they interact through dialogic discourse. Hence, this study adds to our understanding of the social construction of knowledge.

Practical Implications

The findings of this research can provide guidance to teachers in their facilitation of students' understanding of the NOS by explicitly incorporating issues involving anomalous data. Instead of the NOS being taught as a discrete topic in the delivery of a course, this study suggests that it may be integrated into the curriculum and taught when students are actually experiencing those aspects of the NOS while involved in scientific inquiry and addressing anomalous data. Because of the apparent social, tentative, and subjective nature of moral or ethical issues, teachers can more readily engage students in discourse that touches on the many aspects of the nature of science. Finally, aspects of fallacious argumentation can be characterized so that teachers can learn how to guide their students during discussions of socio-scientific issues.

DESIGN AND METHODOLOGY

This study employed a qualitative, emergent design in the tradition of symbolic interaction (Woods, 1992) that examined reasoning associated with the NOS and judgments concerning evidence on socio-scientific dilemmas (Lincoln & Guba, 1985). The goal was to derive taxonomic categories through discourse analysis (Gee & Green, 1998) entailing samples of fallacious reasoning, conceptions of science, and sample performances of thought as a result of dialogic interaction (Wolf, Bixby, Glenn, & Gardner, 1991). In addition to the qualitative measurements, a portion of the data analyses also employed quantitative nonparametric techniques. This "methodological mix" of qualitative and quantitative procedures is driven by practical situational responsiveness, a design strategy advocated by others (e.g. Patton, 1990; Pitman and Maxwell, (1992), and consistent with other science education research on the nature of science (Lederman and Zeidler, 1987; Zeidler and Lederman, 1989)).

Population and Sample

Students representing different developmental backgrounds ranging from high school through college were identified and used in this study. Students were selected from intact groups from the following classes for participation in this study:

• 28 students from 9th & 10th grade general, earth-space science classes; from a diverse alternative education high school;

• 119 11th and 12th grade honors biology, regular biology, and physics students; from a diverse urban high school;

• 101 preservice elementary science methods students (senior college level). from two campuses of the same university.

Procedure, Questionnaires, and Interview Protocol

There were three phases to this study. During the first phase, students were asked to respond to questions in order to assess their conceptions relating to the following areas of the nature of NOS: 1) the tentativeness of science; 2) the role of empirical evidence in science; 3) social and cultural factors in generating scientific knowledge; and 4) creative aspects of science. These issues have been previously used to assess student beliefs in the NOS (Lederman & Adb-El-Khalick, 1998). Students were asked to provide written open-ended responses to the following four questions:

1. After scientists have developed a theory, does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories.
2. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.
3. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?
4. How are science and art similar? How are they different?

During the second phase, students were presented with a socio-scientific scenario modified from Brinckerhoff & Zeidler (1992) that required decisions based on their moral or ethical beliefs . The scenario requires students to react to an ethical issue involving research conducted on animals and required them to offer moral lines of reasoning to justify particular positions. In particular, students were asked to provide their honest opinion to the following topic and questions in the form of written open-ended responses (note that they were also asked to rate the level of their belief conviction based on an ordinal scale):

Animal Rights? Millions of rats, mice, rabbits, dogs, cats, chimpanzees, and other animals are sacrificed yearly in the U.S. in support of many kinds of research. Without their sacrifice, the development of thousands of new vaccines, surgical procedures, drug therapies, tests of potential carcinogens (cancer causing chemicals) and new pharmaceuticals would be restricted or terminated. In recent years, computer models and cell cultures have greatly reduced the need for live animals for many research purposes, yet many crippling and lethal human diseases remain that pose problems so complex that only live animals offer hopes for clues.

1) To what extent do you agree with the following statement? (Circle a number)

Animals should be used for research.

Strongly Agree	0	1	2	3	4	5	6	7	8	9	10	Strongly Disagree

2) Is the conquest of human disease worth the sacrifice or destruction of other species? Why? Why not? Please explain.

3) Do you believe scientists and/or students should be allowed to experiment with live animals? Why? Why not? Please explain.

4) Is there a moral difference between using animals for food and research and using them for clothing and for testing consumer products? Why? Why not? Please explain.

Phase three of the study utilized the selection of 41 pairs of students (within each of the high school and university classes) based on their initial response and level of conviction to the aforementioned scenario and nature of science questionnaire. This resulted in 82 students who were purposefully selected to obtain pairs with different levels of variation (low and high) based on an ordinal scale for their belief convictions. These paired students were then probed with questions from the investigators (modeled from Kuhn, 1991, 1992), designed to elicit their epistemological reasoning and their explanations for causal justification of evidence and to engage them in dialogic conversations that challenged each others reasoning. The investigator interviewed the students using the following questions / epistemological probes:

- Here are your original responses. I would like you to keep these responses to yourself for now and spend a moment to refresh your memory concerning your original responses.
- I would now like each of you to restate your position to one another about to what extent you agree with the statement; "Animals should be used for research" -- and explain the reason for your position. [Justification Probe]
- If you had to convince (the other person) that your view is right, what evidence of proof would you say or show to persuade him / her? [Justification Probe]
- Could (the other person) prove that your were wrong? Why? Why not? [Alternative Probe]
- Could more than one point of view on this matter be right? Please explain. [Epistemological Probe]
- How does either scientific knowledge or opinion play a role in each of your positions? [Epistemological Probe]

Students were allowed to freely interact, challenge and question each other during the interview process. The investigator served as a facilitator and interjected the above questions throughout the interview. After the last epistemological probe had been explored, the investigator provided the students with a fictitious "research news" UPI press release that provided additional anomalous data to the students. The students were told that the report was made by experts in the field last year. There were, in actuality, two UPI reports (see Appendix I) that supported either animal testing or computer modeling for medical research. Each student was given the report that was most discrepant with his or her initial responses to the animal rights questionnaire. The students assumed they had each been provided with identical information. The two reports contained identical information with the exception of the title and occasional appropriate key phrases supporting the alternative positions.

One title proclaimed: "REPORT SUPPORTS ANIMAL TESTING FOR MEDICAL RESEARCH"; while the other title stated: "REPORT SUPPORTS COMPUTER MODELING FOR MEDICAL RESEARCH." After they each had read the fictitious but “official - looking” UPI press release, the students were asked to rate themselves on a 0 through 10 ordinal scale for the following questions:

• Please rate the degree of confidence you have in the authors' findings (0 = low confidence and 10 = high confidence); and,

• Having had our discussions about this topic, and considering the new research information you have read, would you consider changing your position on your original questionnaire --- “Animals should be used for research”? (0=strongly disagree and 10=strongly agree)

Interviews typically lasted between 25 to 30 minutes. Discussions were tape-recorded and later transcribed. This resulted in approximately 533 pages of transcripts. Field notes were also kept and used as a basis for validity checks during the discourse analysis. Issues of validity for discourse analysis were based on convergence, agreement, and coverage (Gee and Green, 1998) by all four authors, and parallels the general criteria for credibility for qualitative data (triangulation of data and member checking) described by Lincoln and Guba (1985). Hence the concept maps that depict the taxonomic categories in the results section were derived by consensus from the four authors using all of the transcripts. At any given time, two of the four authors were always “blind” as to the identity of the interviewees.

DATA ANALYSES AND FINDINGS

The data analyses and findings are presented together to allow for a richer interpretation of the findings. The four research questions and our corresponding interpretations are addressed in this section.

Research Question 1. In what ways do students' views of the nature of science influence their reactions to socio-scientific issues when confronted with information that challenges their initial beliefs?

In order to address this question, the results of student responses to the NOS questions and the STS questions are presented in the form of concept maps which represent the taxonomic categories that were derived by the researchers. This portion of the data analysis was derived in a manner consistent with the iterative processes of data reduction, data display, and verification as suggested by Huberman and Miles (1994). The researchers employed both within-case and cross-case analysis to derive and handle the display of data and analysis of analytic text. Additional methodological considerations may be found in the methodology section above. Each concept map represents an array of responses to each question raised on both questionnaires. Note that a legend is provided that indicates whether particular categories were unique to college students, high school students, or shared by both. Categories considered unique to college or high school students were ones in which a response was either entirely absent in the corresponding group, or the consensus of the four researchers was that a given response was not representative of that group (i.e. less than 5%). These taxonomic categories were derived from the questionnaire responses of 27 college students and 54 high school students (the students who were selected to participate in the interview sessions and for whom complete data were obtained). Each concept map is preceded by a short overview, and followed with sample indicators of responses that were used to construct the map. (Note: all bulleted items are direct quotations.) The summary section examines the specific connections between students' views of the nature of science and their interpretation of socio-scientific issues.

Responses to the Nature of Science

I. Tentativeness

Figure 1 depicts students' conceptions of the tentative nature of scientific theories. Student conceptions range from theories as static and fixed to the idea that they change in quick response to social utility and technological advances.

I. Tentativeness - Do Theories Ever Change?

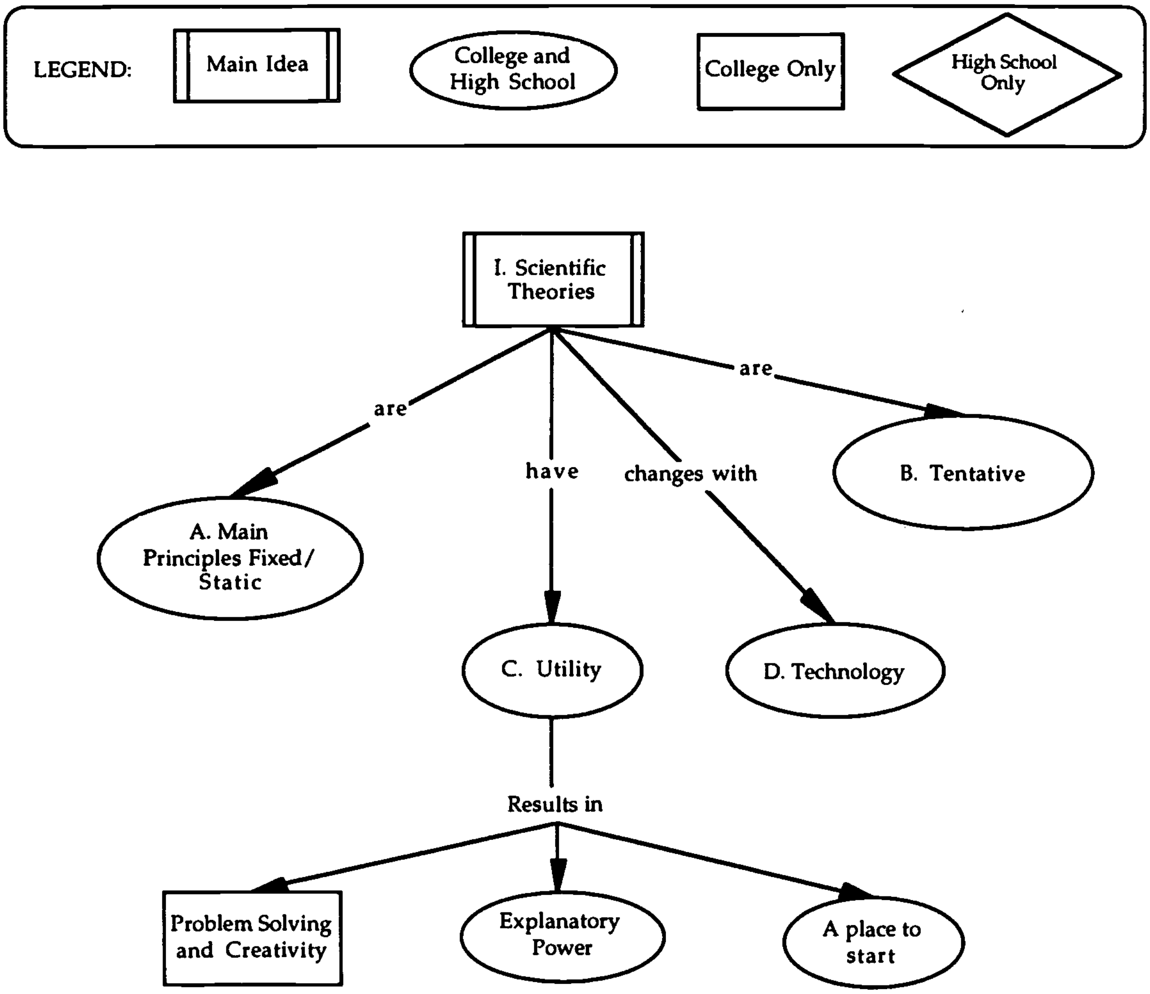

Figure 1. Tentativeness of theories.

A. Static/Fixed

- I do not believe that a scientific theory changes. I believe that a theory has to be tested and retested before it becomes a theory to make sure that it is accurate and will always apply.
- No, once a theory has been proved enough it does not change.
- A theory is a hypothesis that was tested many times by many people. Once the same results have occurred many times it is called a theory. I think that theories can be revised and somewhat changed but the main principle stays the same.

B. Tentative

- Theories change when more information is discovered that may shed doubt on previous ideas.

• Yes theories do change. We teach theories because at the time they are the best answer known to be true.
• The point of a theory, in a strange way, a open call for others to try to prove it false.

C. Utility

• Yes, theories can always change. I believe that it is important to teach scientific theories because the process can aid in everyday problem solving and critical thinking.
• We teach scientific theories as a place to start rather than a carved in stone solution.
• We teach theories to students to explain phenomena. However, theories are meant to be tested and challenged.

D. Technology

• As technology around us continues to advance, more and more theories will be modified or proven false altogether.
• We are presented with new possibilities everyday, new technology that enables us to go more in depth with our research.
• Yes, I do believe that some theories change because of technology. The more advance we become the more you can expand on the thought or theory.

II. Subjectiveness

In attempting to examine the status of scientific knowledge versus opinion, students' responses distinguished between the "subjectiveness" of opinion and the "objectivity" of scientific knowledge. In general, subjectiveness was equated with personal opinions, whereas scientific knowledge was associated with proven, tested, or constructed knowledge. However, the college students demonstrated conflation among various activities of science (theories, conclusions, hypotheses, conjecture) and opinion. These students equated the status of opinions with scientific processes.

II. Subjectiveness - Is there a difference betwen scientific knowledge and opinion?

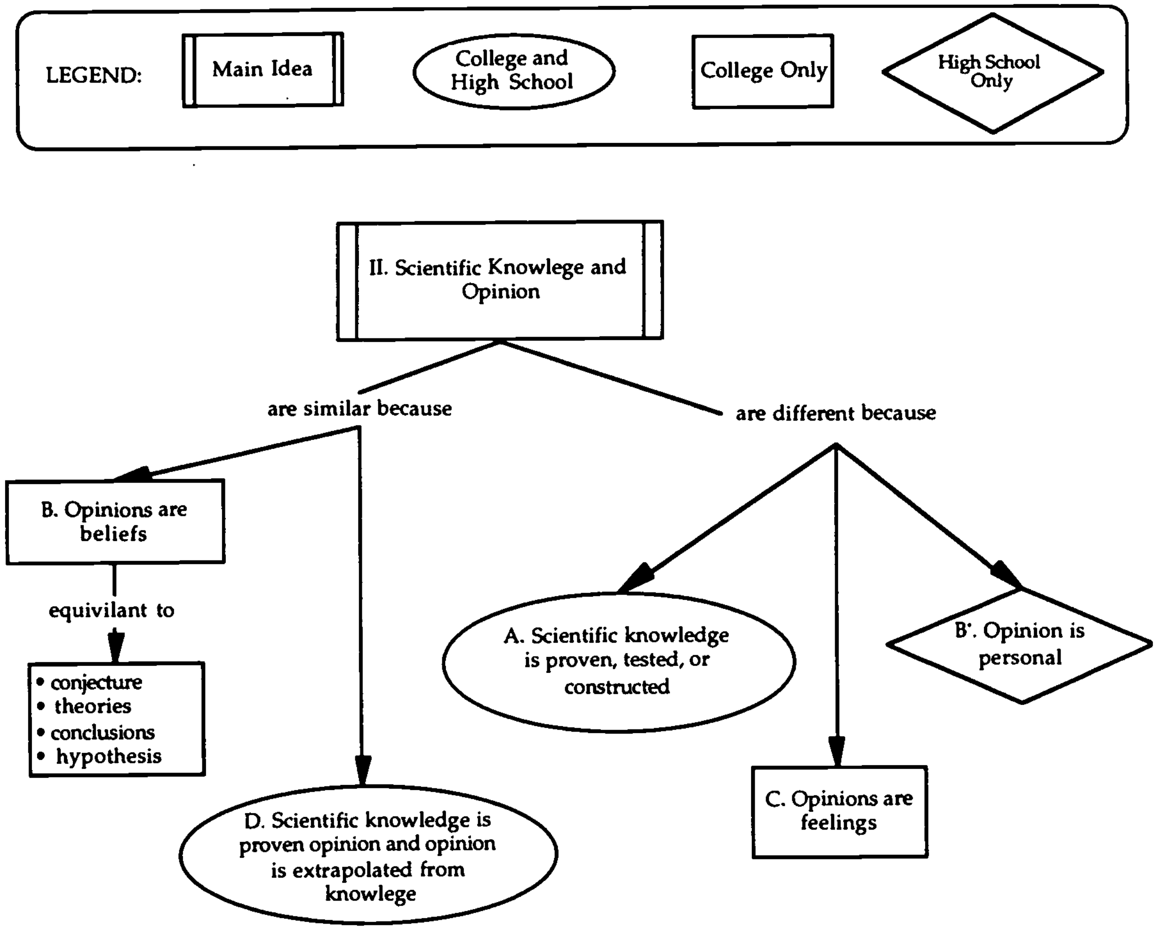

Figure 2. Subjectiveness in science.

A. Scientific knowledge proven/tested

• Scientific knowledge includes facts that had been tested and are now proven true.

• I don't think the knowledge is static - various opinions drive further research.

• Scientific knowledge is based on proven facts and data...

B. Opinions are beliefs (same as science concepts - theories, etc.)

• Scientific opinion is based on theories. An example would be the evolution theory. Some people have different opinions about this due to their beliefs.

• An opinion of that (solar system) however would be theories of how the planets are created, life form on other planets, besides earth.

• If we make a statement about a theory then it can be assumed as an opinion because theories have not been proven for sure.

B'. Opinion is personal

- Opinion is what one person thinks.
- When someone has an opinion about something, they are what they think about that topic or subject.
- If I was to believe that the earth was flat, well it's scientifically proven that it's not ... it would still be wrong but that would still be my opinion.

C. Opinions and feelings

- An opinion requires little qualifying other than a person's own knowledge and feeling about an issue.
- An opinion is one person's interpretation or feelings about something.
- Opinion... is how one feels about something such as the creation of the world. Some believe that God created the world and others believe that the world was created by other forces, chemical reactions.

E. Scientific knowledge is proven opinion

- One man's knowledge is always another man's opinion and vice versa.
- Scientific knowledge can always be an opinion but has facts or proof behind it to back it up.

III. Theoretical commitments and the cultural / social role in science

The effect of cultural and social factors on scientists' theoretical commitments was explored in question three. Most students seemed surprised that it was possible for scientists to arrive at different conclusions while examining the same data. It is interesting to note that college students expressed distrust in the scientists' possible interpretation or manipulation of data to fit their beliefs. Both college and high school groups also expressed the possibility that the data was missing or incomplete. It is also interesting to note that some high school students could not entertain the notion that the scientists could be observing the same data and rejected that claim outright.

III. Cultural/Social roles in science. How are different conclusions possible from same data?

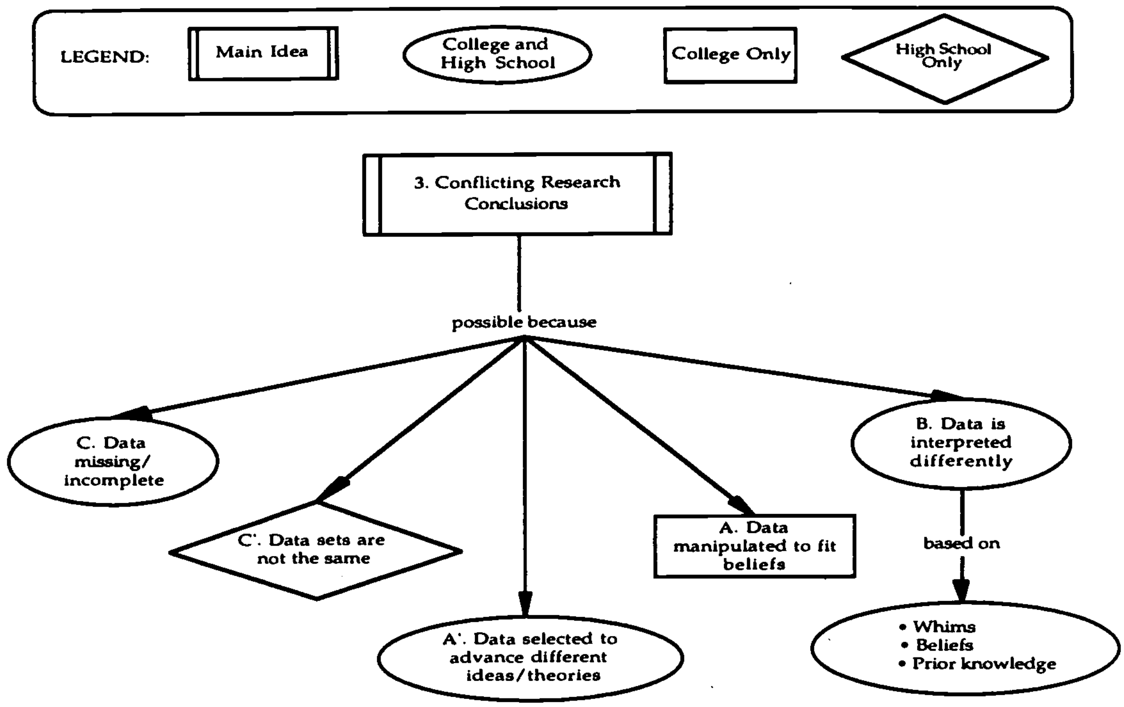

Figure 3. Cultural / Social roles in science.

A. Data manipulated to fit beliefs

• It is human nature to distort data so that it supports our personal beliefs. Half empty or half full is a good example. There are endless pieces that can be added to or taken from a puzzle to make it our way.
• I think there are different components to experiments and different scientists look at different time frames and data. Also, maybe the data is somehow manipulated.
• ... There is not enough evidence to confirm the theory in one direction or the other. ... The 'people factor" stretches the research.

A'. Data selected to advance different ideas/theories

• One must get others to come to the same conclusion before it becomes widely accepted. You must remember that bias are present and that any picture can be painted (numerous types) with the same paints - what it is is the artist's interpretation of said paints.
• This is where theories come in and each scientist tries to formulate his/her own idea and find the needed evidence to support it.

• ...different scientists are assuming some criteria to fit their belief of whether or not the universe is expanding or shrinking.

B. Data is interpreted differently

• People interpret things differently and that does not mean that one person is right. One scientist may have more background knowledge than another.
• The facts that have been gathered may be the same, but different scientists may draw different ideas (opinions) about these facts.
• All of the scientists could be looking at it from different perspectives. All of their opinions are different.

C. Missing/incomplete

• The data these scientists are looking at is incomplete...these beliefs as to the universe expansion (or shrinkage or whatever) have very little solid evidence to back them up, making these theories purely the opinion of the scientist.
• There may also be not enough sufficient information or data so these scientists are assuming some criteria to fit their belief.
• There are different conclusions because there is not enough evidence to confirm the theory in one direction or the other.

C'. Data are not the same

• Maybe they are not looking at the same data or the calculations are off.
• Maybe some astronomers believe that the universe is expanding due to ideas that they can't really tell if it is and new stars are always popping out of nowhere.
• No one knows where the center of the universe is, therefore we are unable to decide weather we are moving toward or away from it, or staying in the same place in relation to the center.

IV. Empirical/Creative

Students generally perceived connections between art and science in terms of the creativity each employ that stem from human passion and a sense of exploration. However, a distinction seems to be made between the "activity" of science -- which does involve a type of passion and the "spirit" of art which is more directly linked to emotion. A somewhat disturbing finding is that by the time students reach the senior year in college, many perceive science as a rote and clinical process.

IV. Empirical/Creative. How are art and science similar? different?

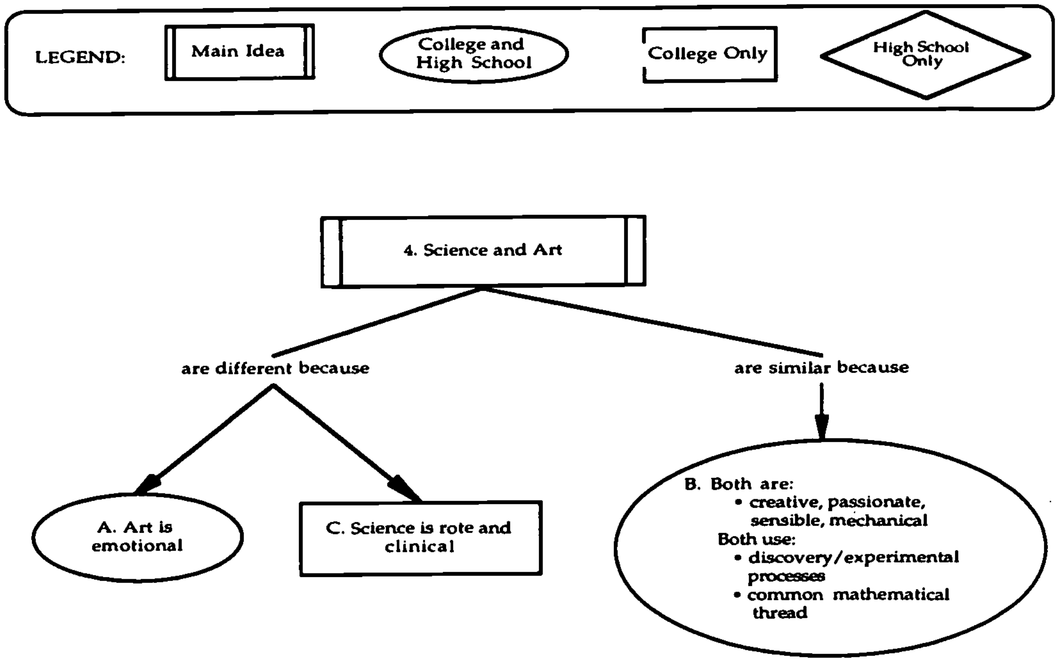

Figure 4. Empirical and creative aspects of science.

A. Art is emotional/aesthetic

• Art is about expression, feelings, and portrayal of emotions.

• They are different because art is "beauty in the eye of the beholder" each person get different feelings from each piece.

• They are different in the fact that art is sometimes based on feelings and emotion.

B. Science and Art are similar (creative, make sense)

• Science and art are similar because each require a little inquisitiveness, and an ounce of weird in each profession to create strange yet wonderful things.

• Science and art are the same in that a great deal of original thought is involved in both. Creative minds are a must in both fields, also there can be a common thread of mathematics and geometry in both fields.

• Science is like art in the essence that they are both extraordinary and mysterious. Many people can interpret a painting in several ways just like they would interpret science in different ways.

C. Science is rote / clinical

• They are different because not everyone could try to make a drawing by exactly what they see, but a science experiment can be performed by following directions.

- Science has guidelines and formulas to follow.
- Science deals with things in a clinical sense...

<u>Reasoning on Socio-Scientific Issues</u>

II. Conquest of human disease worth destruction of species

When reasoning about socio-scientific issues related to medical research and its impact on other species, students evoked three broad ethical orientations that focused on scientific, religious, and social values. It is interesting to note the religious orientation consisting of polar values -- student interpretations of the intentions of God are in the eye (and belief system) of the beholder. Also of interest is the ethical justification of some college students for attributing a lower status to "death row" inmates in place of animals for scientific research.

2. Is the conquest of human disease worth the sacrifice/destruction of species?

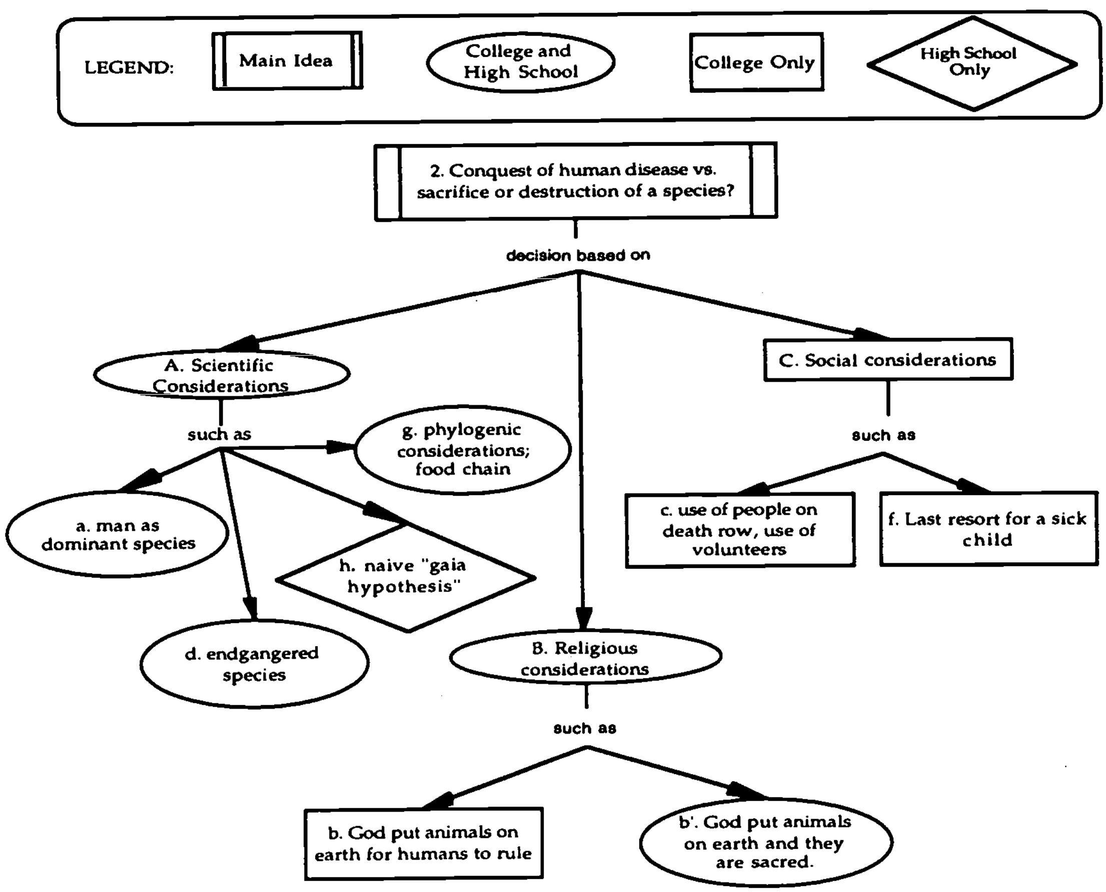

Figure 5. Conquest of human disease vs. sacrifice of species.

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A. Scientific considerations

• I would not believe in killing/using extinct or endangered animals for testing.

• I believe that the animal species and the preservation of the species directly affects the survival of humans.

• ...disease is a natural function of the world. Other species should not have to suffer to cure our illnesses.

B. Religious considerations

• I do not believe that animals have souls. Therefore, I believe in using them to help humans that do have souls.

• My belief is religious in nature because I believe that God put animals on earth and placed man in dominion over them.

• I feel animals are just as sacred as people. God create humans as he did animals. What right do we have to take their life away for research purposes.

C. Social considerations

• (Animals) should only be used if;

1. There is no other way to find cures.
2. The disease is very serious and widespread.
3. The animals used are not particularly sentient.

• Testing may be too cruel for humans, but test death row inmates - use the scum of society for testing.

• No, other species should not be destroyed for our gain.

III. Live animal experimentation

Students' views on the acceptability of live animal experimentation were qualified with limited uses for "valid" research or in the case of naturalistic settings. Those who took the counter stance tended to cite attributes of sentience for animals. Of particular interest was the tendency of high school students to cite the immaturity of their classmates who would "abuse" the opportunity to perform experimentation on live animals.

3. Should scientists and/or students be allowed to experiment with live animals?

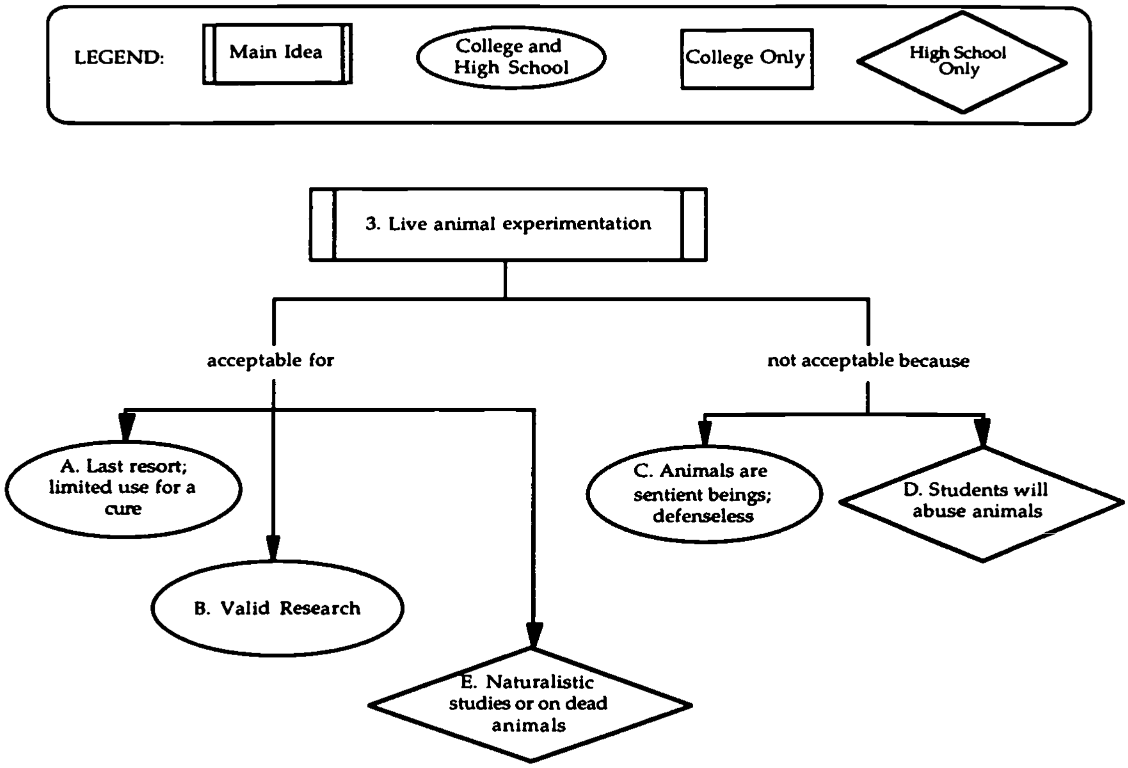


Figure 6. Experimentation with live animals.

A. Last Resort

- Only if it is for valuable information - such as a new drug for cancer or some catastrophic reason...a last step and final results.
- My feelings are that live animals should only be used as a last resort.
- If you are in a situation where you could possibly invent or produce a cure for a terminal illness then why not just go for it.

B. Valid Research

- It depends on the intent of the experimenter. If he/she is simply trying to observe how a live animal reacts to having a perfectly good limb amputated, then no.
- I believe scientists should be able to experiment with live animals for valid purposes. I don't know if students have a valid enough purpose.
- Students and scientists should be allowed to experiment with live animals under strict regulations. These should include the number of animals and the degree of pain inflicted in the animals.

C. Sentient beings/defenseless

- No. Because animals feel pain just like humans do. Why should we be able to inflict pain on defenseless animals for our research purposes.
- No. Animals feel pain just like humans. People wouldn't think to experiment on a live person so why use an animal?
- Why can't we use life sentence prisoners for testing...why must we pick on poor animals?

D. Students will abuse

- I think scientists are extremely smart and mature students should be allowed to experiment...but if it were high school students I would say no because they probably would abuse their privileges.
- Students would goof around too much and act crazy. Plus, since they really don't know what they are doing something could happen.
- Some students may not know when they have gone too far with an animal and they may hurt it other students may be immature and they may abuse the animal in some way.

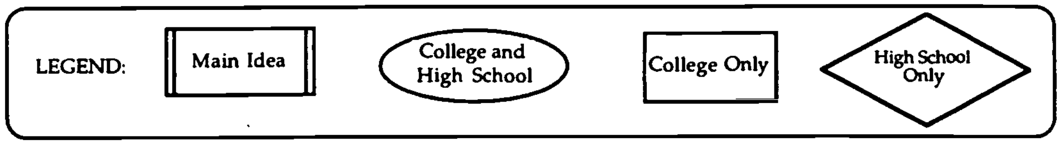
E. Naturalistic studies/dead animals

- It's nice to experiment with live animals, how they eat, sleep, and live. Animals should be treated like humans with self-respect, and dignity.
- Why do we have to do experiments on them and hurt them, where as we could just study them in their own natural environment without even touching them.
- I don't believe students &/or scientists should kill healthy animals & dissect them. If an animal dies naturally or has an illness then those could be used for dissection.

IV. Moral differences

The fusion of religious values with scientific epistemologies was present in college students reasoning about the use of animals in medical or consumer research. The quotations reveal conflated religious and scientific views. Other students distinguished among degrees of necessity, usually between medical and consumer ends to justify the means for animal research. The following concept map shows the students' views concerning the use of animals for scientific research.

4. Moral Difference Between Use of Animals for Food/Research vs. Clothing/Testing of Consumer Products



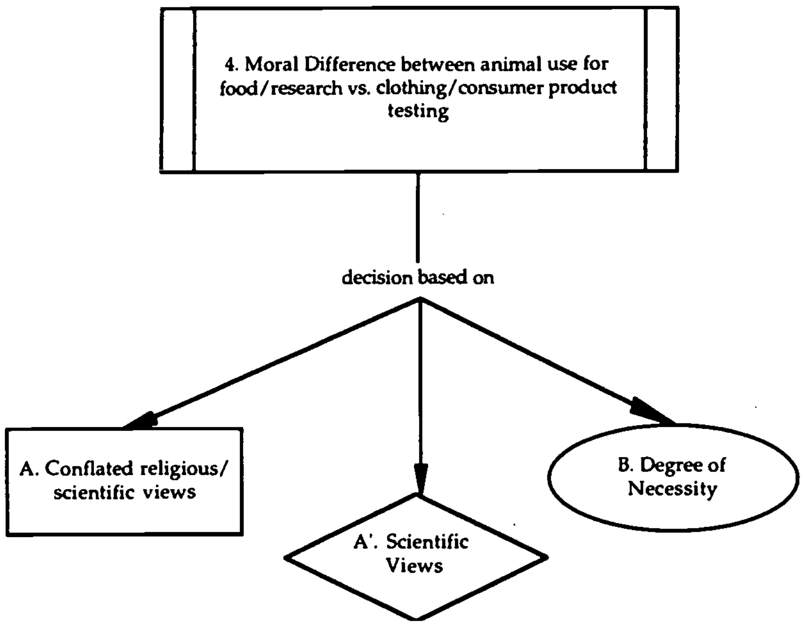


Figure 7. Medical versus consumer research on animals.

A. Conflated religious and scientific views

• God put animals on earth so that the life cycle would keep on going. The stronger predator will win.

• God put them here as part of the food chain and in times past they were necessary for clothing.

• I believe that animals were put on earth to help us survive.

A'. Scientific Views (not religious based)

• Animals and humans are in the same food chain and I believe they are here as a means for survival for humans.

• ...we all need food and are part of the food chain.

• No. There is no difference, because there must be a reaction for every action. So if you put an action on an animal it will have a reaction.

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B. Degree of necessity

- Research and testing consumer products is for the good for the human. It furthers the world of medicine...animals used for clothing is a waste...they are being killed for selfish motives and not helping to improve anything except maybe fashion.
- Yes, because using them for food is essential, and research could be to help the animal.
- Using animals for food and research is more important than for clothing and consumer products.

Summary for Research Question 1.

While the above concepts reveal students' selected conceptions of the nature of science and their beliefs about the use of animals in medical research, a more detailed analyses of the transcripts during the interview portion of this study reveal patterns of thought that further elucidates how one's NOS views influence their reasoning on socio-scientific issues. Literally dozens of instances of this phenomenon were identified by the investigators. Several selected examples of interest are presented to demonstrate the dynamic relationship between NOS views and students interpretations of ethical issues in science. It is important to remember that some of the dialogue was in response to certain probes designed to reveal the personal epistemologies of students in this area.

In the following selection, a student's response to how scientists may interpret data differently indicated her belief that different scientific views were merely a matter of personal opinion and scientists would interpret data to support their own personal beliefs. When probed about her viewpoint about animal rights being based on opinion or scientific evidence, her response confirms that she selectively looks for evidence that supports her opinion.

> My viewpoint isn't anywhere near science, I think it is just what you believe. You just go from there. ... I'm real stubborn, if I have my viewpoints no matter what that sign says, I think, 'I don't believe that they (animals) really go through pain' and more important to me is the benefits. .. I think I change the channel when I see ... what they go through. I leave it on for how it benefits us.

Again, in response to the same question above, another student suggested that scientists can calculate things to "look the way they want." This particular viewpoint, although cynical, but perhaps truthful at times, tempers her views about socio-scientific issues. The position that scientists have hidden agendas was brought up and reiterated in numerous interviews.

> ...We don't have the factual information (medical research) and a lot of what we see is propaganda...most definitely they don't tell us everything.

Another relationship between students' NOS views and their reasoning on socio-scientific issues is revealed when one student indicated her view on the importance of empirical evidence in scientific research. She stated that scientific knowledge requires "proven facts and data," but opinion, while possibly including facts, is not provable. Yet, when pressed how scientific evidence plays a role in her position about the ethical treatment of animals, indicates a rather narrow and one-sided view of the role of empirical evidence and "proven facts and data."

> I guess most of it is opinion, but some of it is based on personal research, magazine articles. I was never aware of any of this and a guy I work with -- he was a PETA campaign person and he would hand out this stuff ... on the ethical treatment of animals and the brochures they sent me said that in most of the cases of animal research, it is not necessary and it is not as accurate as testing chemicals and medications through a computer. ... After I started reading it, it really changed my mind and influenced me a lot.

Another interesting finding was the extent to which students compartmentalized scientific knowledge versus personal knowledge and opinion. Although certain students viewed scientific knowledge as that which is supported by concrete evidence and facts, they would not consider the use of scientific evidence to convince other people to change their personal opinions. It would appear that these students felt that opinions are immune to change despite any concrete evidence provided that supports alternative viewpoints.

• But, M. has her own (opinion) and I have my own and I think we are entitled to that, so I would not try to convince her towards my opinion.
• I would never try to change any one's opinion because it is their opinion, it is their core being... all you can do is speak your opinion and say, 'can you imagine this, this, or this.' You can't force anyone's opinion.
• You know, just like I have mine (opinion), you have the right to yours. But, it is what you feel like, not what other people come up with.

Research Question 2. In what ways do students utilize evidence that conflicts with their initial core beliefs about socio-scientific problems?

Dialogic thinking and argumentation occur when the discourse of one individual compels another to coordinate his or her reasoning structures with those of the first individual. This type is discourse has been cited elsewhere in the literature (Berkowitz, 1985; Kuhn, 1992; Zeidler, 1997) and suggests that each person's assertions that run counter to another's (particularly where belief convictions are at odds) creates mutual dissonance. An example of how dialogic reasoning and argumentation challenged core beliefs between two students is illustrated by the following dialogue. Notice how each person is cognitively challenged during discourse to reflect on either his or her beliefs, assertions, and premises, and those of the other individual. The resulting discourse leads to a joint construction of shared social knowledge (although not necessarily shared beliefs). By engaging students in discourse on socio-scientific issues, greater understanding of how students come to evoke aspects of the nature of science through dialogic reasoning is attained. The fact that students construct their knowledge through personal experience (and belief systems) when responding to anomalous data or information is also evident in the following exchange:

D - I was thinking like if you think humans are a superior species, then it would probably be safe to assume that monkeys are the next in line because they are so similar to humans.
N - Mine is based on religion. Humans have a soul, animals don't. That is where I draw the line that humans,

> the value lies there -- So I don't believe that a monkey does.
> D - If you detach yourself from a rat or rabbit. But if you test yourself on a monkey -- Monkeys are amazing. Chimpanzees nurture their children like humans, they communicate. ... Even physical features are so similar. They almost have an opposing thumb. So how do you feel about testing on primates and things?
> N - I look at my children and I say, if a monkey could save my child's life I would probably be willing to give up the monkey's life. ...
> D - What about cloning? Do you think clones have souls?
> N - No!
> D - Then it would be okay to test on clones?
> N - Oh my God, I don't know D. I don't think there is an answer to that.
> D - Well if you don't think they have souls then it should be okay.
> N - I don't know. How do you know if they do (have souls) or not? They would be human? I don't know that!

Research Question 3. How do an individual's belief convictions change when confronted with discrepant evidence?

In order to explore the reconciliation of personal beliefs with anomalous information, this study addressed the relationship between the students' level of conviction to their initial beliefs and their willingness to change beliefs once challenged. Social implications in the development of scientific knowledge are just one aspect of the nature of science that needs to be more explicitly examined and taught to students. To address this question, nonparametric procedures were performed on all the subjects who participated in the interview portion of this study. Because of the exploratory nature of this study and the limited interactions during the interview, an alpha level of .10 was agreed upon by the authors to increase sensitivity for detecting pedagogically imported (statistical) patterns or trends in data. The following five null hypotheses were constructed:

H_o1: There is no significant difference between pretest and posttest responses on students' belief conviction about animal research.

H1: There is a significant difference between pretest and posttest responses on students' belief conviction about animal research.

A Wilcoxon Sign Rank (Univariate) test was performed using the entire sample (n=80) to examine whether or not changes in their preliminary belief convictions occurred following the interview discussions and review of the fictitious articles. The alternative hypotheses was supported (p=0.0001), suggesting that students' views had been altered from their original position after discussions about socio-scientific issues and exposure to anomalous data.

H_o2: There is no significant difference between college and high school students' degree of confidence in the "research news" UPI press release.

H2: There is a significant difference between college and high school students degree of confidence in "research news" UPI press release favoring higher scores (increased confidence) for high school students.

A Wilcoxon Rank Sums test was used to detect if differences existed between groups regarding their "sensitivity" to authoritative information. It was assumed that because of the range of high school students (freshman through seniors) that they would employ less "skepticism" and have more confidence in a given research report (as well as being influenced by their peers). A significant difference was found between college (n=28) and high school (n=53) students' degree of confidence in the fictitious research reports (p=0.06).

H_o3: There is no significant difference between college and high school pretest responses on belief conviction about animal research.

H3: There is a significant difference between college and high school pretest responses on belief conviction about animal research.

H_o4: There is no significant difference between college and high school posttest responses on belief conviction about animal research.

H4: There is no significant difference between college and high school posttest responses on belief conviction about animal research.

Hypotheses 3 and 4 above were tested using a Wilcoxon Rank Sums test to see if appreciable differences exist between college and high school students' initial and post-interview survey responses concerning their belief convictions about animal research. In both cases, the null hypotheses was not rejected (H3 p=0.68; H4 p=0.97). This suggests that there was homogeneity of variances existed between the groups (although this was not a major concern because of the nonparametric assumptions). More importantly, however, it does help to highlight the importance of having the taxonomic categories derived through the qualitative portion of this investigation. While there were no detectable differences between these groups (on this admittedly short ordinal scale) -- the qualitative taxonomies (as illustrated by the concept maps above) do occasionally point to varied conceptions related to their belief convictions about their reasoning regarding socio-scientific issues and the Nature of Science between college and high school students.

H_o5: There is no significant relationship between students' posttest responses on students' belief conviction about animal research and their degree of confidence in the "research news" UPI press release.

H5: There is a significant relationship between students' posttest responses on students' belief conviction about animal research and their degree of confidence in the "research news" UPI press release.

The Spearman Rank Order (Rho) test was performed to determine if relationships existed. It was found that weak (r=.20; p=0.06) correlation's existed between students' convictions on these ethical issues and their confidence in the research reviews. (If the difference scores are used (pretest to posttest) the correlation to the confidence scores becomes r=0.29; p=.008). In either case, this finding suggests that there are small, but subtle, relationships that might interact and mediate between these two factors. No claim to causality is implied by this finding; perhaps future experimental and qualitative studies could probe the nature of this relationship further.

Research Question 4. (a) To what extent is fallacious reasoning a mediating factor in the students' dialogic reasoning when confronted with viewpoints contrary to their initial core beliefs about socio-scientific issues? (b) If informal fallacies are found, what is the nature of their reasoning?

Elements of fallacious reasoning were present in the interviews of the students. Many examples of formal and informal fallacies have previously been reported (Zeidler, Lederman, and Taylor, 1992; Zeidler, 1997). The unique focus in the present investigation was to examine the nature of more common informal fallacies as they occur through dialogic interaction about socio-scientific issues. Four common fallacies were selected to demonstrate how students responded to anomalous information from other students. The nature of the fallacy is discussed in each of the following examples:

• **Confirmation bias:** One student who is had strongly disagreed with the use of animals for medical research, demonstrated a seminal example of confirmation bias in her reasoning. The connection between her belief persistence regarding the abuse of animals and her evaluation of new evidence that runs counter to her viewpoint is evident in the students response in how he/she would account for that discrepant evidence:

> I don't know again I would have to listen to both of them how is this doctor or scientist able to use no animals and find cures and what are you doing wrong that you have to use animals. ... if someone came to me with all the information, here is all the people that were saved and you saw the people or you saw the statistics who was saved and what they did. My concern would be the animals, how did it hurt the animals .. Did they inject Chemo and see how long they suffered ... I would want to see the statistics more on the animals.

Note that the implicit assumption in the student's explanation for the alternative point of view is that it stems from a priori assumption of faulty methodology. This reasoning strategy has the effect of serving as a self-selecting filter to evaluate only confirming evidence in support of one's ethical position on a socio-scientific issue.

• **Validity Concerns:** In the following selection, the student may be able to accept data or arguments contrary to his/her own beliefs, but remain "agnostic" or reject the validity of a claim because of the mediating effect that emotive considerations bring to bear on a problem which may conflate the validity of alternative data or information. It is clear in this example that the tacit beliefs and inferences students bring to bear on a problem may conflate the validity of alternative data or information:

> ... the pictures are more powerful because that hits your emotional side so that you know the facts are they help you make up your mind if you are looking at it logically and rational. But, it you see a picture then your emotions are going to come into play no matter what you do. ... If you are shown a picture of a war where 10,000 men are being bombed and one little dog walks through the thing and gets bombed and everyone starts crying. But, it's seeing the innocence of it, its like a baby that cries and you feel for the baby because of the innocence of the child and, it's like that for the animal. You know the facts are good and the facts are the best way if you are going to look at it logically -- (we are) going to think with our emotions.

• **Normative Reasoning:** A fairly regular occurrence was that students frequently referred to previous personal experience and used those experiences to argue their point of view. This tended to occur with such regularity that their subjective and highly personal experiences played a constant role in mediating ethical judgments on socio-scientific issues. The following is typical of the extent to which normative social factors influenced students reasoning:

> See, I have been through an experience like that. My aunt had MS. She passed away about two years ago. With something like that it is completely awful to see somebody go through and if it came down to that, I would say, primate or not, let's find what works. Just because seeing the deterioration and all -- and I would feel bad for the animals -- but of course you're talking about a family member. But just nobody, no person should have to go through those kind of things. Any method that we could find to reach a cure for that even if it doesn't work, we know that that doesn't work now.

• **Altering representation of argument and evidence:** Consistent with prior research (Zeidler and Schafer, 1984; Kuhn, 1991), students discussing socio-scientific problems often exceed the "boundaries of evidence" provided in a fictitious scenario. Students, at times, add pragmatic inferences to the arguments under consideration by allowing their personal beliefs to mediate the argument at hand. In the following example, a student uses anthropomorphic reasoning to endow a sense of utilitarianism and purposeful means-to-ends decisions for primates.

> My grandmother has arthritis. She is in another country but they are doing testing on her to see if it could help her and possibly other people. I mean, sure the animal has no say in it, but I am sure that if they did, they would agree to it.

The partner's response takes on the same anthropomorphic reasoning and exceeds the boundaries of evidence when she adds the following pragmatic inference during their discussion.

> One (issue) that comes to my mind is the chimpanzees in the Air Force. They were exposed to radiation. They taught these chimpanzees to fly planes. Then, you know, they dropped the bombs and the fallout. Chimpanzees were actually exposed to radiation.

SUMMARY AND IMPLICATIONS FOR SCIENCE EDUCATION

The data analyses indicated that common fallacies were present during dialogic discussions involving anomalous data (the use of "evidence" that opposed a particular belief conviction). Students were found to assert prematurely, accept, or refute a generalization on the basis of a sample that was neither sufficiently large nor representative. This inadequate sampling of evidence may lead to the fallacy of hasty generalization and appear to be rooted in inadequate sampling practices. Some students also inserted pragmatic inferences into the dilemma or problem by factoring their personal beliefs into the fictitious scenario. This resulted in the misinterpretation of initial evidence and was consistent with other forms of altering representation of argument and evidence found in previous studies (cited above). The present study, therefore, supports a situated-cognition viewpoint that is consistent with the social construction of knowledge . Thus, the importance of providing students with the opportunity to engage in critical and reflective thinking to foster scientific literacy cannot be over-emphasized (Zeidler, 1997).

Some science educators have argued that explicit consideration of the social contexts of the nature of science is necessary, even at the expense of some content to provide students with an opportunity to view science as a social enterprise embedded in a community of scientists (Driver, Leach, Millar, & Scott, 1996). Consistent with this claim, Lederman (1992) asserts that a better understanding of complex, situational variables that mediate teachers' pedagogical decisions is preferable to examining an isolated teacher characteristic or a single instructional variable. The present qualitative study presented an array of conceptualizations that revealed contextual links between the nature of science and the social enterprise of science via socio-scientific issues. This approach, therefore, reveals the "sociologics" of science (Latour, 1987) to students by providing a pluralistic view of scientific thinking, reasoning, and discourse.

In this study, we explored the tangled web of views between students' perceptions of the nature of science and their reasoning on ethical issues associated with socio-scientific problems. We also sought to bring to light subtle differences between college and high school student views related to the same issues. The use of dialogic discussions involving anomalous data not only enabled the researchers to probe for epistemological conceptualizations of these topics, but provided students with an opportunity to engage in metacognitive reflection via the interactions among peers and the probing questions provided by the interviewer. It is our contention that science classrooms can provide a rich forum for the exploration of disparate viewpoints. Students' perceptions of the activity of science do appear to impact how they evaluate information pertinent to socio-scientific problems and the ethical issues implicitly embedded within those problems. By engaging students in discourse on socio-scientific issues, teachers can challenge students' moral and ethical beliefs, which can lead to explicit instruction in teaching many aspects of the nature of science. Explicit instruction on the NOS embedded within relevant socio-scientific issues provides concrete, real-world examples that are important to the students; hence NOS concepts may be anchored to a cognitive framework readily accessible to the students. Based on the level of engagement for students in this study, we find that students are more likely to "buy in" to a given science topic or investigation if it is based around social issues they deem important. With a more robust understanding of the NOS, students will be more likely to address moral and ethical dilemmas from a scientific point of view (evaluation of evidence, integrating multiple perspectives with own metacognition (reflective thinking) etc.) leading to better informed decision making.

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APPENDIX I

RESEARCH NEWS

REPORT SUPPORTS COMPUTER MODELING FOR MEDICAL RESEARCH

(*UPI*) A report recently released by the U.S. Medical Research Council indicates that computer modeling for medical purposes is a major method of improving the treatment of human disease and injuries. In a comprehensive study of over 100 medical schools and medical research centers, it was reported that over 300 new treatments were developed since 1996 using recently developed computer programs. Included in new treatments were vaccines for childhood diseases, pharmaceuticals, and advances in surgical techniques. U.S. Surgeon General Jocelyn Elders called the report "A convincing study supporting the use of computer simulation techniques for legitimate medical research."

Opponents of computer modeling dismissed the report as propaganda, describing the findings of the Council misleading and irresponsible. Dr. Robert Gray, Professor of Anatomy and Physiology at Vanderbilt University and spokesperson for the animal testing group Humans First, called the report "an immoral outrage against animals" and "a poor excuse to continue causing needless animal suffering." Council members responded to the criticism by citing the numbers of people benefitting from the research, including several critically ill children who have recovered following treatments developed using computer modeling.

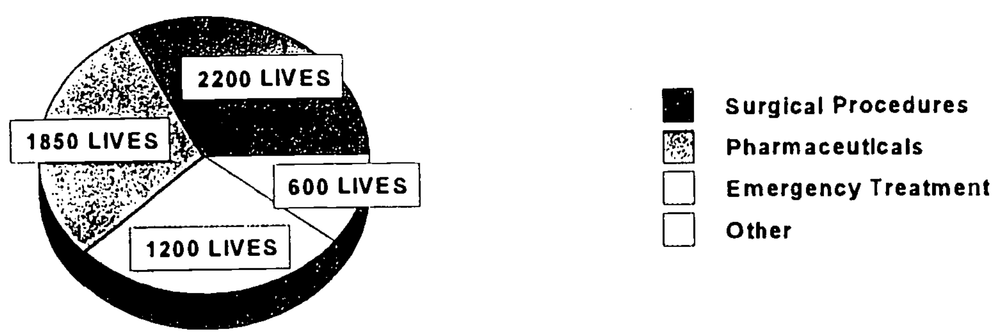
Dr. Janice Bernstein, Director of Pediatric Surgery at Johns Hopkins Medical Center, hailed the findings as "concrete proof that the benefits of using computer models far outweigh the negatives." Bernstein described the opponents of computer modeling as having "their priorities in the wrong place. If it comes down to killing a thousand animals just to develop one medicine versus saving the lives of hundreds or thousands of animals by using modern computer and chemical technology, it is positively immoral to turn our backs on the suffering animals."

Among the most significant treatments recently available as a result of computer modeling are:

- A vaccine used to prevent several strains of the deadly liver disease Hepatitis C;
- An antibiotic which is used to combat the bone-destroying bacterium *Clostridium lacunea* in patients with compound fractures;
- A surgical technique which has been used to repair deformed heart valves in newborn children.

According to the Council's report, recent medical research using computer models has saved the lives of no fewer than 100 newborns and 50 adults during 1997 in the United States alone, and has been the primary successful medical treatment of over 2500 adults in major medical centers (see chart below). Surgeon General Elders sympathized with the opponents of computer modeling, but concluded "Although some would like to think that it is necessary to use animals in research, modern technology has made animal testing obsolete. After all, who among us would volunteer our pets to be given an experimental vaccine and then be intentionally infected with hepatitis or HIV [AIDS virus] just to see if the treatment works?"

LIVES SAVED BY COMPUTER MODELING SINCE 1996



Source: United States Medical Research Council

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RESEARCH NEWS

REPORT SUPPORTS ANIMAL TESTING FOR MEDICAL RESEARCH

(UPI) A report recently released by the U.S. Medical Research Council indicates that animal testing for medical purposes is a major method of improving the treatment of human disease and injuries. In a comprehensive study of over 100 medical schools and medical research centers, it was reported that over 300 new treatments were developed since 1996 using animals such as dogs, monkeys, and chimpanzees. Included in new treatments were vaccines for childhood diseases, pharmaceuticals, and advances in surgical techniques. U.S. Surgeon General Jocelyn Elders called the report "A convincing study supporting the use of animals for legitimate medical research."

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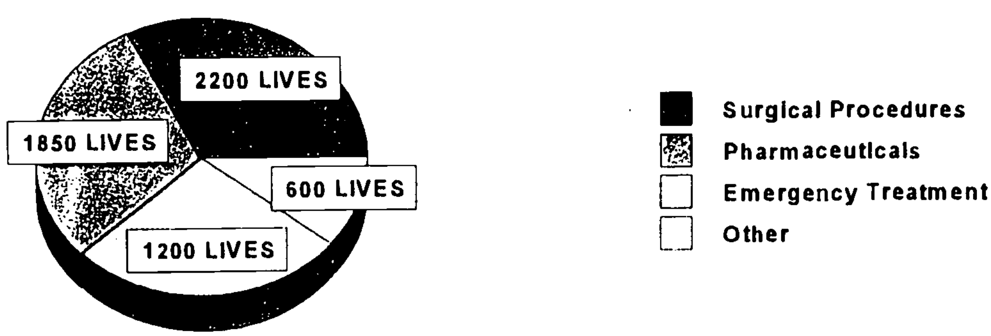
LIVES SAVED BY ANIMAL TESTING SINCE 1996



Source: United States Medical Research Council

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