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AUTHOR	Black, Carolyn B.
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ABSTRACT

This paper outlines a three semester hour undergraduate, core course in Scientific Inquiry that increases student knowledge and advances student skills in understanding science as knowledge, process, and human enterprise. This course was developed as a bridge between science and the humanities and a bridge for entry-level students in the development of attitudes and understandings of methods used in scientific research and enterprise. The sample for the study was 54 undergraduate college students in a private urban Catholic 4-year college with an enrollment of 2,700 students. In comparing the pretest and posttest survey, student beliefs about science were still localized around content or "body of knowledge." Surprisingly, students views moved away from the process view "exploring the world." (PR)

Scientific Inquiry : A Bridge

Carolyn B. Black, PhD

Incarnate Word College
San Antonio, TX 78209

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Carolyn B. Black
Incarnate Word College
San Antonio, TX 78209

Abstract:

This paper outlines a three semester hour undergraduate, core course in Scientific Inquiry that increases student knowledge and advances student skills in understanding science as knowledge, process, and human enterprise. This course in Scientific Inquiry was developed as a bridge between Science and the Humanities and a bridge for entry-level students in the development of attitudes and understandings of methods used in scientific research and enterprises. Students of Scientific Inquiry gain a background in the historic, cultural, and philosophical position of science and technology. Student reasoning processes, through the use of "experiential metaphors," have a chance to develop as they gain a more immediate understanding of how science is done by actual experience with scientific problem statement, experimental design, data collection, data interpretation and the drawing of conclusions. Reading and interpreting primary and secondary source science writings and producing written and oral critiques and commentaries permits students to participate in some of the various research models of scientific inquiry. Overviews of essential ideas and current challenges in physical, chemical, biological, geological and space science fields provide a broadened understanding of the scale and proportion of science and what scientists in these various fields do.

In order to determine their entering scientific attitude development, students were pretested using a 16-item selection from the Views of Science, Technology, and Society instrument developed by Aikenhead and Ryan. Areas of understanding that required further developmental experiences and which could be expanded using "experiential metaphors," were noted. In order to observe qualitative changes in student perceptions and understandings of science and technology and its relationship to society, students kept portfolios which were collected at formative stages. These student writings reflected their attitudes and understandings of material presented. Quantitative results of pretesting and posttesting of college students is reported. Students were surveyed again after eleven weeks of class and their views on science, technology, and society were compared with the earlier survey results.

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Carolyn B. Black
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San Antonio, TX 78209

INTRODUCTION

A major public concern in the United States is the decline in the number of undergraduate majors in science and engineering and the lack of scientific literacy among students not majoring in science or engineering. The future of the United States as a leader in the world depends upon the availability of a pool of scientifically literate persons from which to train not only engineers, scientists and technicians but also the business, commerce, and governmental decision-makers who can and will need to make well-informed decisions on matters that directly impact the safety, well being, and future of our society. American universities and colleges need to develop their science major and non-major students to be able to participate more ably in the world of science and technology.

The importance of undergraduate science courses was recently addressed by Sigma Xi, The National Scientific Research Society (an honorary society of 115,000 scientific research and engineering members in 500 chapters and clubs in the North America and around the world). The theme of their national meeting (1989) was Science Education at the Undergraduate Level. This theme, one of the major concerns of the society, will be repeated again in 1994, this time for Kindergarten through twelfth grade levels. Seven major recommendations for undergraduate science course improvement as brought forward by a select advisory group of research scientists were:

1. Quality of Instruction -- The importance of good teachers, knowledgeable in learning theory, over researchers who may not be as well prepared to teach was emphasized.

2. Quality of Curriculum -- Entry-level courses should be appropriate and interesting. Courses more rewarding to students should be explored.

3. Quality of Human Environment -- Faculty is inaccessible in large classes -- not preferred in entry-level classes. Courses often are barrier, or weed-out courses. More positive support is needed for women, minorities and the physically challenged. Mentoring at all levels was suggested.

4. Quality of Physical Environment -- Hands-on experience with the investigation of phenomena was suggested. Students should have experience with scientific critical thinking, planning, analysis, and synthesis and the opportunity to discover the integrity of data, the uncertainty of measurement and through these, the development of understanding of the the powers and limitations of science and engineering. It was recommended not to use computer simulations as a substitute for hands-on experience with the investigation of phenomena.

5. Accessibility and Flexibility of Curricula is Essential for Student Mobility -- Interchanges between disciplines, and interdisciplinary flexibility is recommended. UG education should not be frozen in a tightly sequenced discipline only.

6. Attitudes and Perceptions of Students, Faculties, Administrations and the Public -- In charting policy for undergraduate education in s/m/e, bringing about changes in attitudes and perceptions must be a part of any effective policy.

7. Addressing the special needs of traditionally underrepresented groups in s/m/e, i.e., women, minorities, physically challenged. Student learning styles, particularly global view points versus linear logic, should be considered.

Scientists and engineers are not the only groups concerned with the problems of undergraduate science and engineering education. The National Association for Research in Science Teaching (NARST), an international association of science educators, has recently developed a networking group of undergraduate college science teachers concerned with the enhancement of UG science education experiences for all students. Further work in this direction is on-going at the time.

The development of methods for the advancement and improvement of undergraduate science education is also addressed by the Society for College Science Teachers (SCST), a wing of the National Science Teachers Association (NSTA) which is associated with the American Association for the Advancement of Science (AAAS). The SCST looks into research and reform initiatives in college science instruction. SCST is also concerned with education in the basic sciences and health professions, an important concern for the whole country.

Recommendations from the American Association for the Advancement of Science in the widely-known book, The Liberal Art of Science: Agenda for Action (1990) include the consideration of science as a liberal art. "Liberal education," this report says, "is the most practical education because it develops habits of mind that are essential for the conduct of the examined life." Further, "The experience of learning science as a liberal art must be extended to all young people so that they can discover the sheer pleasure and intellectual satisfaction of understanding science"....and "be empowered to participate more fully and fruitfully in their chosen professions and in civic affairs." Further recommendations suggest that science should be taught as science is practiced at its best, a description of which includes an understanding of the methods and processes of scientific inquiry.

RATIONALE

A course, therefore, in Scientific Inquiry, organized to develop students' understandings of what science is, what science can and cannot do, including an view into the history and philosophy of science, and an understanding of what the inquiry of science has revealed about the natural world would be an important introduction assisting the growth of student abilities. Scientific Inquiry, in opening up an avenue of communication between people-explaining-the-world and people-experiencing-the-world, can act as a bridge between the Sciences and the Humanities on the one hand, and a bridge between naive-thinking habits of the entering student and the development of habits-of-mind related to scientific problem-solving on the other hand.

This course in Scientific Inquiry is designed to increase student knowledge and advance student skills in understanding science as a process, and as a way-of-knowing. It adds to student understanding of how science is done and distinguishes between science and technology. In addition, it helps students develop attitudes that promote an interest in learning more about science and applying the methods of science to their own problem-solving. Gaining greater familiarity with how science and scientists inquire into the nature of the universe helps students to increase their awareness as citizens no matter what subject field they are majoring in, and provides students with a better understanding of the scientific and technological workings of the complex world we live in.

The challenge is to present science not only as a collection of knowledge (content) or the workings of processes, but also as a human enterprise. To this end stories from the history and considerations from the philosophy of science are presented. College students, aware of the struggles and concerns of individual scientists as they face the mysteries of nature, identify, thereby, with the human input into science that is often lost when only the so-called "facts" are presented, a limitation often found in courses in the major specialized areas of science.

COURSE OVERVIEW

This course uses lectures, group discussions, inquiry experiences, "experiential metaphors," observational sharpening skills, and assistance with learning-about-learning science. Initial teacher-student discussions search for a definition of science and technology. Human factors impacting the questions of science and the problem-solving of technology are considered. Limitations, constraints, controls, risks, and costs of technological innovations are referenced to ongoing everyday occurrences in the local and world neighborhood. An understanding of the origins (historical) of science and technology, methods by which knowledge of the natural world is acquired, examined, corrected and used are examined. Methods of observation, acquiring evidence, and using inference from evidence are practiced. Students identify and discuss inductive and hypothetico-deductive methods of examining phenomena (philosophical). Students use guided design principles (Wales, Nardi & Stager, 1986) identified for basic engineering courses in decision-making processes. The differences between researchers and practitioners is noted. Discussions of many areas of science (emphasizing the grand theories from biology, physics, chemistry and geology) give students an idea of the breadth of science -- from quark to quasar.

Student awareness of scientific inquiry is awakened as a series of experiences. Experiences, demonstrating various methodological concepts, were developed and are used as "experiential metaphors," simple and symbolic systems, that can be referred to later as students develop a greater understanding of the methods of scientific inquiry. In support of their own experiences, students are provided the opportunity to practice non-threatening, classroom-initiated investigations in hypothesis-formation, data analysis, inference drawing, discussion of results, and conclusion statement, which prepares them for statistical studies in the future. Individually and in groups, students do comparative studies with observations made over time, and experimental studies with control of variables. Experience with analysis, generation of new ideas, synthesis, and evaluation of ideas are presented. Having done simple examples of research and reported it themselves, students can bring this knowledge to the reading of a paper in a scientific research journal. Scientific articles in popularized publications are also read and comparisons are drawn between these and peer reviewed articles. Finally, students, under the concept of mastery learning, produce a portfolio of their writings as evidence of their progress and learning. This portfolio is something they take from the course for reference and for their own pride in learning.

THE STUDY

The purpose of the study was:

1) to determine the level of entering student views on science and technology, the influence of science and technology on society, the nature of scientific knowledge, and the construction of scientific and technological knowledge,
2) to plan experiences and learning possibilities to address and advance the level of understanding of concepts such as science and technology, the influence of science and technology on society, the nature of scientific knowledge, and the construction of scientific knowledge and technology, and
3) to observe changes in student perceptions of science and technology, the influence of science and technology on society, the nature of scientific knowledge, and their construction of scientific and technological knowledge.

Subjects

Taking part in this study were fifty-four undergraduate college students in a private urban Catholic four-year college with an enrollment of 2700 students. The introductory college core course, Scientific Inquiry, is a course required for graduation and usually taken in the freshman year of college. Eighty-three percent of the members of the two classes were women. Sixty-five percent of the classes were Hispanic-named students. Science and nursing majors made up 46% of the class with professional degree seekers in education and business making up another 26%. Eight percent were undecided about a major, and 20% were in other liberal arts fields such as English, communication arts, interior design, fashion merchandising, political science or music. The students' ages were mostly 17-20 years (69%) with eleven percent age 21-24, fifteen percent 25 or older, and five percent unreported.

Method

A survey of student views on science, technology and society was given as a pretest to determine the students' scientific attitudes and attitudes about science and technology. The Views on Science, Technology and Society (VOSTS) developed by Aikenhead and Ryan (1992) and administered as a national survey to Canadian students in grades ll and 12 was the instrument used. From a battery of 114 multiple-choice items, 16 items were chosen, each of which had between nine and eleven possible student positions in response to a statement. Three items defined science and technology, seven items were concerned with the influence of science and technology on society, three items permitted reflection on the nature of scientific knowledge, and three other questions dealt with professional decisions and communications of scientists and technologists. Students were asked to respond with the answer that matched their view in response to the statement. Students were further instructed to respond with their own written response if they could not find a response that matched their view.

The instructor's presentation of materials and in-class student experiences relating to science, technology, the influence of science and technology on society, the nature of scientific knowledge, and the construction of scientific and technological knowledge was based on the levels of response of the students and on the definitions and explanations of these concepts developed by a panel of scientists and science educators on the National Council on Science and Technology Education of the American Association for the Advancement of Science (AAAS, 1989). Also used as a basis for an understanding of the nature of science were John A. Moore's description of the nature of science (Science as a Way of Knowing, Vol. VII, Part III, pp. 82-95.) and

Chapter Two of Ernst Mayr's The Growth of Biological Thought (pp. 83-132).

The same items from the VOSTS survey were administered eleven weeks later as a posttest to determine changes in views of the students as a group.

Students were also requested to write their reflections on the classroom presentations and experiences for their portfolios and hand them in for teacher reflection, response and commentary.

RESULTS OF SURVEYS

Presenting an entering survey, referred to here as a pretest, allowed the instructor to determine student levels of understanding and concern for science, technology and their relationships to society or the public that could be addressed in instruction. A final survey, referred to here as a posttest, offered comparison with student entering views. The survey provided for three non-responses to the statements offered: I don't understand, I don't know enough, and none of these choices fits my basic viewpoint. In the last selection, students were encouraged to state their own viewpoint also. Where percentages in the following results do not add to 100%, the responding students may have selected one of these choices, or the majority attitude was reported only.

What is Science and Technology?

Students' perception in defining science (VOSTS 10111) was mostly (39%) related to content, that science was a body of knowledge. Another 26% viewed science as exploring the world and discovering new things, a process approach. No students considered that science was an organization of people using processes to discover new knowledge. Twenty-four percent saw science as improving the world, an instrumentalist viewpoint that confuses science with technology. In the posttest, although fewer students (12%) held instrumentalist viewpoints and fewer (14%) also considered the process approach, a greater percentage (68%) confidently moved to the position that science was a body of knowledge. The percentage of students considering science a human activity using process to discover new knowledge improved slightly (4%).

In considering the definition of technology (VOSTS 10211), 37% of the entering students realized that technology dealt with ideas and techniques for designing and manufacturing things, organizing workers, business people and consumers and for the progress of society, a very mature understanding of the workings of technology. An almost equal number (30%), however focused only on the instrumentality of technology that brings new instruments, tools and gadgets to everyday life. Amazingly, only a small percentage (13%) held to the popular, but narrow, North American myth that technology is only applied science. In the posttest, majority support (55%) moved to the understanding that technology dealt with ideas and techniques for designing and manufacturing things, organizing workers, business people and consumers and for the progress of society, a maturing attitude. However, one third of the students (33%) returned to the narrower view that technology was applied science.

In distinguishing between the contribution of science to technology and technology to science (VOSTS 10411), 87% of the respondents were originally aware of a clear distinction between, but mutual assistance in, the relationships of science and technology. This understanding was increased to 98% in the posttest view.

Science and Technology's Influence on Society

In considering North American heavy industry and pollution (VOSTS 40161), 72% of the students initially recognized a responsibility to be concerned with pollution problems in the immediate environment and not to transfer pollution problems to undeveloped countries. Subsequently, posttest students responded in a slightly higher percentage (77%) to the same concern.

In making future energy and future world food production and distribution decisions (VOSTS 40211, 40217) most students (52% for energy, 57% for food) recognized that scientists, engineers, and the public should be concerned equally, while 24% (energy) and 19% (food) were willing to leave such decisions to scientists and engineers while also involving the public. At posttest, all students upheld the point-of-view that future energy and food production decisions should be made with the input of scientists engineers and the public, most (74% and 67%) preferring equal representation (D) of the three. Fewer students (12% energy: 14% food) felt that decisions should be left to scientists and engineers and only involve the public.

Concerning science and technology's helpfulness in dealing with difficult social problems (VOSTS 40411), 56% of the students realized that it was not so much science and technology helping with the solution of problems as it was people using science and technology wisely. However 28% believed that science and technology caused many of the problems. Seven percent believed that science and technology could help solve some of the social problems, but not others. There was very little change in the posttest views of science and technology's ability to solve social problems; most students (58%) were still of the opinion that people need to use science and technology wisely, and some (26%) suggested, again, that science and technology are a cause of problems.

In relation to scientists' and technologists' own response to print and TV media reports (VOSTS 40441), 41% of the students thought that the scientists and technologists could be influenced by the media as well as others except in their own area of expertise. Others (35%) gave scientists and technologists credit for being trained to think logically and being able to either know the correct information or able to check it out. In the posttest an equal division of student opinion about scientist' ability to resist being fooled by the media was expressed. Some (42%) granted that scientists were only human and could be fooled and an equal number (42%) expected them to be knowledgeable or circumspect concerning media stories and reports.

In the consideration of science and technology being able to correct presently unsolvable pollution problems at some future time (VOSTS 40451), 67% of the students recognized that science and technology alone cannot solve these problems but that the public must insist that the solution of these problems be given top priority. Thirty-two percent held the slightly fatalistic opinion that no one can predict what problems science and technology will be able to fix (D) and that problems may become so bad they are beyond fixing (C). It was interesting to note that no students blamed science and technology for the pollution problem (A) or held the completely fatalistic view that nothing could be done to fix the problem (B). Posttest students felt more confident (86%) that pollution problems could be fixed if everyone deemed it their responsibility and top priority (E). Fewer (12%) felt the challenge of pollution was beyond prediction (D) and solution (C). None believed that success with solving pollution problems in the past assured success in pollution problem solving in the future.

Professional Decisions and Communications of Scientists

Eighty percent of the students were aware that scientific theories needed the support of the consensus of scientists (A-C) (VOSTS 70231), and of that group 46% were further aware that peer considerations are helpful in revising and updating a theory (C). Only 14 % believed that scientists, when proposing a theory, did not have to convince other scientists (D-F). Over 90% of the posttest students were aware that scientists must present their theories to other scientists and achieve consensus (A-C). Only 7% (half of the pretest number) believed that scientists did not need to convince other scientists (D-F).

In relationships between the press and scientific research teams' announcements of new discoveries (VOSTS 70321), a remarkable 82% of the students wanted to see the research team present the discovery to other scientists first in order to test, verify, or improve the discovery and prevent inaccuracies in stories that are published (D-E). Only 15% wanted the research team to announce a discovery directly to the public (A-B) or be free to decide who hears about it first (C). Later, in the posttest, 95% of students supported presentation of discovery to other scientists (D-E). The remaining five percent wanted the research team to be free to decide who should hear about it first (C). No later student opinions suggested release of discoveries directly to the public.

Technological Decisions

In the consideration of putting into practice a new technological development when scientists have not explained why it works (VOSTS 80121) 49% of the students queried were concerned that scientists should be able to explain why it works first (A-C). Another 42%, however, were aware that new technologies do not have to be explained by scientists, with 35% of the students requiring that the decision to put it into practice depends on "a number of other things: how well it works, its cost, its efficiency, its usefulness to society, and its effect on employment"(E). A majority of posttest students (54%) still believed that the use of a new technology depends on whether a scientist can explain why it works. However, more students (46%) were aware that it depended on a number of things (E).

The Nature of Scientific Knowledge

In the understanding of scientific models and modeling (VOSTS 90211), 32% of the students said that scientific models are copies of reality (A-C), and another 41% took the middle ground (D) that scientific models were close to being copies of reality based on scientific observations and research. Seventeen percent held that scientific models were not copies of reality (E-G), that they were helpful but had limitations, they change with time and our knowledge, or because they are educated guesses. Posttest students evinced a greater understanding of the role of models in science. Fewer (21%) believed they were true and copies of reality (A-C), and more (21%) understood that they were helpful, limited, changeable, and enlightened guesswork

(E-G). However a healthy majority (54%) took the middle ground (D) that they were close to reality and based on observation and research.

Item 90311 asked students to consider classification schemes as classifying nature according to *the way nature really is,* and asked for their position on this consideration. Twenty percent of the pretest students (A, 5%; B, 15%) believed that classification schemes identified the way nature really is, but 76% recognized that scientific classification schemes were somehow constructed by scientists (C-F). In the posttest, students were even more confident (81%) that models were scientific constructs (C-F). However, 14% still held that classification schemes were nature as it really is (A-B).

With the question of whether scientists discover or invent hypotheses (VOSTS 91012) 63% of the students held that scientists invented hypotheses (D-F), and 29% suggested that scientists discovered hypothesis as being there all the time, based on experimental facts, or being found by methods invented by scientists (A-C). More posttest students (73%) understood that scientists invented hypotheses, and slightly fewer (23%) held the view that scientists discovered hypotheses.

Summary of Results of Preliminary Survey (Pretest)

Student ideas and beliefs concerning science and technology were colored by their past experiences in high school and their own life experiences. Students were not really clear on the distinctions between science and technology, although they were aware that they were somehow related. Ideas of technology were concerned with the "latest technology," such as instruments, tools, and gadgets. Having heard much about technologically related problems, students felt that the public should be equally concerned and involved in decision-making related to science and technology, often because they believed that science and technology cannot go it alone. A major portion of the students believed that scientists had to be able to explain why new technological developments worked before the product should be used. Students were not firm on their understanding of scientific models, but were more acquainted with classification scheme models as used in biology. Students were not completely sure about whether scientists proposed or discovered hypotheses.

Summary of Results of Follow-up Survey (Posttest)

Following eleven weeks of experiences and presentations in Scientific Inquiry student views changed. Beliefs about science were still localized around content, "body of knowledge," a return to the familiar terminology and a surprising move away from the process view "exploring the world," with very few selecting an answer that suggested that scientists (people) were involved in the process of creating new knowledge. Beliefs about technology, however, were improved as students moved from technology being gadgetry (C) to an understanding of the processes (E-G), or more narrowly, technology as the application of science (B). Students were well aware of the interdependence of science and technology. The equality of the relation of the public with scientists and technologists in decision-making in energy production and food production and distribution was highly supported by students. Students were still of the opinion that people needed to use science and technology wisely. Students were both aware of the human ability of scientists to be fooled by the media and yet showed respect for the scientist's ability for finding the right answer despite the media. Students had a realistic but confident view of the responsibilities of scientists, engineers and the public. Only slight fatalism in regard to problems was displayed. Students wanted scientists to critique and refine each other's work. Students were more investigative than pragmatic and were concerned with explanations of why new inventions worked and wanted scientists to find out why. More students understood the relationship between models made by scientists to explain phenomena and "reality." Students also better understood the role of hypothesis construction in scientific inquiry.

SCIENTIFIC INQUIRY AS A BRIDGE BETWEEN EXPERIENCE AND UNDERSTANDING

In presenting Scientific Inquiry as a bridge between student experience and student understanding of science and technology it is important to consider first what the student's experience and understanding might be when s/he enters the classroom at the college level. This foray into a more student-centered direction in developing curricula for students in introductory and entering levels needs to be established on the basis of the intellectual needs of students especially for our changing and challenging entering students. It is also important that the instructor be aware of and have a broad base of learning in the sciences and about the sciences, and an understanding of learning theory for how to apply the most successful methods to the various experiences that can be developed for a class in scientific inquiry.

For this curricular invention, several "experiential metaphors" were developed. These consisted of classroom experiences based on the learning cycle in which students participated and from which various concepts and thinking skills related to the understanding of scientific inquiry were able to emerge. As these experiences were developed, they could be referred to so that one concept could be built on another as students observed the ways in which scientists developed ideas into theories and then tested these theories. Examples in support of these developing concepts often came from the history of science, from the most current scientific writings, the daily newspaper, or from questions from the students themselves. In viewing the history of science, students reviewed how science and technology had changed the primitive world of our ancient forbearers, medieval progenitors, and more recently our grandparents.

Students were led into an understanding of scientific inquiry in some of the following ways: (1) Classroom discussions of What is Science, What is Technology, and the Relationship between Technology and Society develop the students' vocabulary for further discussion and extension of such concepts. (2) Students come to understand the concept of hypothesis generation by generating their own original and falsifying hypotheses from a set of data and then testing the data to determine support for their hypotheses. (3) Students develop the concept of modeling by developing a classification scheme for a set of objects and determining the criteria for category membership; other examples of models are also presented. (4) Students select an investigation from their own surroundings to study. In doing so they make an hypothesis, determine methodology for study, take data, interpret data, discuss results, draw conclusions, and make recommendations for future investigations. (5) Students experience the differences between observation and experimentation by doing observational and experimental investigations and comparing them. Experience is also provided in using constants and variables. (6) Students are shown their way around the scientific literature in written and database form. Students gain an appreciation of the differences between primary and secondary references and video reporting by critically analyzing these media offerings. (7) Finally students may display the scientific inquiry abilities gained in this course by a final production of a paper, an experiment, or a field experience and a portfolio. During the course, concurrent news happenings in the world of science are brought to the attention of student and their attention to science stories in the news is encouraged.

Assessment of students is made by reports of their classroom inquiry experiences, their own inquiry experience, a first midterm consisting of matching, fill in the blank, critical problem solving, and 2 out of 5 take-home essay questions, a second midterm consisting of a critical analysis of one primary and one secondary science source of their own choosing, and a final evaluative portfolio with their reflections of various new concepts they have gained during the course, their corrected papers, and answer to questions based on historical readings.

Conclusions and Implications

Scientific Inquiry qua Scientific Inquiry (rather than focused only on environmental problems, for example) by using and allowing students to experience scientific inquiry may be beneficially presented as an introductory course or core course. The use of instruments such as the VOSTS at the beginning of the course is helpful in understanding student ideas about science and scientific inquiry. Knowing student understandings, concerns, and entry-level beliefs provides a basis for planning the direction, depth and thrust of a course in scientific inquiry. A course in scientific inquiry should probably not be permanently structured, but allowed to take on the scientific information-of-the-moment in order to bring students momentarily into the realm of the scientifically intellectually endowed. Students can be given the responsibility of planning a scientific inquiry of their own and then employ their effort as a springboard to understanding of how scientists investigate phenomena.

Students do not have a firm idea of what science and technology are or how they are interrelated. Many educated adults do not. We call this scientific illiteracy, but it is also technological doltishness. Although it is important for science majors to have a broader understanding of their field, which they may not be offered in strictly content-centered courses, it is also important for science non-majors to understand where, why, and how knowledge of their world is gathered, accumulated and related in science, and how it is used and controlled in technology. Students need to know that technology is based on design limited by nature and man's laws, that it concerns risks (good and bad) and needs to have built-in controls for which humans are ultimately responsible. Such understandings help students to see that science and technology are not some mysterious "big thing going on out there" over which no one is knowledgeable and no one has control. It offers hope to a generation often observing things out-of-control in their surroundings.

Students begin to develop a respect for themselves as researchers and users of technology when they better understand the place of science and technology in their lives. Methods of scientific problem solving can be shown to be useful in students' lives and in solving problems in their local areas. Guided design problem solving, presented for student consideration, opens the ideas from technological problem solving to their everyday experiences.

As concerns the efficacy of the use of the VOSTS instrument, it is the belief of the investigator than many times students taking such an inventory looks for words and catch phrases with which they are familiar, and will seek out statements that have words with which they are more familiar as answers. Since the investigator did not teach to the vocabulary of the test, concepts that were not stated in the same terms that were used in classroom discussions but held similar meanings were passed up for shorter or more conventional terms such as "applied science" for technology and "body of knowledge" for science, which are both narrow, but partially correct responses.

Students' insistence that they, as part of the public, should be included in energy and food production decisions with scientists and engineers may suggest that students feel that science is more comprehensible and explainable and that a partnership of this nature may be a possibility. The interesting question yet to be posed is how students, as the public, will develop enough of an understanding of science and technology to really function as co-advisors.

"Science," it has been said, "is one of the liberal arts and should be taught as such." (AAAS, 1990, p. xi). It is only as students, scientists, non-scientists, and science educators understand what science and its sister, technology, are and what they do that science can be treated as one of the liberal arts. Student education is unfinished if they are not aware of the fact that science and technology have been brought to them through the organized human curiosity called scientific inquiry and its sister in technology, engineering.

Recommendations:

1. At course introduction: Survey students to determine student interests and levels of understanding of science. Personalizing of the course is recommended where possible.

2. Student development of understanding of journal articles by doing an inquiry experience, writing it up in journal format, and later reading and comparing a journal article with the format used in the student write-up.

3. Discussion and practice of words representing basic concepts in scientific inquiry. Scientific concept, science, technology, research, inquiry, observation, classification, identification, comparative studies, laboratory experiments, experiments-in-nature (field experiments), hypothesis, data, question, observation, inference, results, discussion of results, conclusions, implications, crediting of references.

4. Teaching students learn-how-to-learn-science skills such as taking lecture notes, writing questions while reading, answering questions, creating comparisons, concept attainment, concept mapping, analysis, idea generation, synthesis, evaluation.

5. Mastery learning. Correct student papers at formative stages to see how they are progressing and to offer assistance by comments and corrections. Have students correct papers and put in portfolio. Expect the best.

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