A WORKING MODEL FOR EVALUATING ACADEMIC EXCELLENCE IN GEOSCIENCE EDUCATION, UNDERGRADUATE, AND K-12

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ABSTRACT

Consensus regarding criteria for academic excellence in geosciences is an important component in developing K-16 geoscience study that can lead to 1) general geoscience literacy for personal and social decision making and public support of geoscience research, and 2) strengthening depth of understanding for geoscience majors.

A systhesis of criteria for academic excellence in geosciences is derived from the criteria for excellence developed by scientific societies including National Research Council/National Academy of Sciences documents which address K-16 education in the sciences and geosciences. National professional organization reports corroborate the scientific societies' criteria. By identifying and synthesizing the learning goals in these documents a succinct set of criteria for academic excellence in the geosciences is developed.

Using the Geoscience Academic Excellence Model derived from the synthesis it is possible to evaluate the excellence of academic documents involving the study of geosciences K-16. Geosciences departments are encouraged to develop their own curriculum alignment with the criteria and to assist state and local K-12 science education policy in achieving the same level of excellence.

Keywords: Education-geoscience; education-precollege; education-undergraduate; education-science; education-testing and evaluation; geoscience-professional affairs and public affairs; geoscience-teaching and curriculum

ACADEMIC EXCELLENCE AND GOALS OF GEOSCIENCE EDUCATION

Consensus regarding criteria for academic excellence in geosciences is an important component in developing K-16 geoscience study that can lead toward two primary goals for geoscience education: 1) general geoscience literacy for personal and social decision making and public support of geoscience research, and 2) strengthening depth of understanding for geoscience majors. The first goal is the essential foundation upon which the second can be achieved.

Undergraduate and K-12 geoscience education faculties are revising curricula to meet changing scientific needs, academic, and social demands. Revisions in geoscience are keeping pace with science education reforms and in some cases leading the way among the sciences in implementing reforms. Higher education is beginning to be held accountable for the quality of K-12 education, principally because K-12 teachers are prepared in our institutions of higher education. With the inclusion of the geosciences in the K-12 curriculum it follows that future and present teachers need to learn the basics of the geosciences in undergraduate departments.

The inclusion of geosciences in K-12 schooling leads to a similar expectation of inclusion in undergraduate general education and an opportunity to enhance the geosciences in the undergraduate curriculum. Geosciences departments are now in a pivotal position to influence and implement the two primary learning goals of geosciences in alignment with the national science education reform criteria. Faculty are in a position to assist K-12 teaching colleagues and to build upon K-12 efforts as students move into undergraduate classrooms.

Looking at the national perspectives on science education in the 2000's, it is apparent that if we are to achieve our goals for geoscience education we need to align our efforts with the *National Science Education Standards* (*NSES*), developed by the National Research Council /National Academy of Sciences (NRC/NAS). The *NSES* provide the primary science education reform context that is comprehensively inclusive of the geosciences. The level of excellence established by the *NSES* and affirmed by other national professional documents is, therefore, the level to which we need to address reforms in geoscience curricula.

This study looks at excellence in the light of definitions of excellence derived from current knowledge in the scientific community delineated in its policy documents. By identifying and synthesizing the learning goals in these documents, a succinct set of criteria for academic excellence in the geosciences can be developed. The synthesis can be used in K-16 geoscience curriculum reform.

Using the Geoscience Academic Excellence Model derived from this study's synthesis it is possible to evaluate and achieve excellence in various K-16 geoscience documents delineating undergraduate program curricula, syllabi, texts, state and local K-12 standards and curricula. Geosciences departments are encouraged to develop their own curriculum alignment with the criteria and to assist state and local K-12 science education policy in achieving the same level of excellence.

NATIONAL STANDARDS: ACADEMIC EXCELLENCE AND SOCIAL JUSTICE

The National Research Council of the National Academy of Sciences released the *National Science Education Standards* in 1996. Committees and working groups of scientists and educators, appointed by the National Research Council engaged in a four year process development. The *National Standards* are a product of national professional consensus establishing the credibility of the National Research Council document. The *National Standards* provide goals for learning for all students, emphasizing the need for areas of content learning and equal opportunity to learn successfully. They define excellence both directly and indirectly.

The *NSES* can be the foundation upon which undergraduate programs model their own reforms. The *Standards* provide a guide to the basics upon which a geosciences majors curriculum is conceptualized, based, and extended. Criteria for excellence synthesized from the *NSES* and other national professional and scientific societies documents can be a useful reference for determining excellence.

CRITERIA OF ACADEMIC EXCELLENCE

The criteria for excellence in scientific literacy presented in documents of the National Research Council/ National Academy of Sciences (NRC/NAS, 1993; NRC/NAS, 1996; NRC/NAS, 1999), and the Biological Sciences Curriculum Study (BSCS), (BSCS 1993), corroborated by the American Federation of Teachers (AFT) (AFT, 1998) and the Fordham Report (Fordham, 1998), will be synthesized and presented as a working model for evaluating excellence in geoscience education.

National Scientific Community Documents - National Science Education Standards (NRC/NAS)

The National Research Council's *National Science Education Standards* are based on exemplary practice, research, and a systematic development reaching consensus in the national scientific community. The *NSES* describe the vision for excellent science education, including attainment by all students of an understanding of science that offers personal fulfillment, the use of scientific information and scientific habits of mind. Informed decision making and an ability to increase economic productivity through use of science knowledge in their lives are also goals. The *NSES* "define what students should know and be able to do after 13 years of school science." (NRC/NAS, 1996, p.11-15)

The theoretical base of *The National Science Education Standards (NSES)* is stated as a vision:

> "All students, regardless of age, gender, culture or ethnic background, disabilities, aspirations, or interest and motivation in science, should have the opportunity to attain high levels of scientific literacy." (National Research Council/National Academy of Sciences, 1997, p. 3). The vision is based on decades of research in science education and cognitive sciences, referenced in the *NSES* and the American Association for the Advancement of Sciences (AAAS), *Benchmarks* (AAAS, 1993, p. 327-377).

The actual learning requirements in the *NSES* are described in several carefully framed formats identified as content. Content standards are organized in grade spans of K-4, 5-8, and 9-12. Content is defined to include unifying concepts and processes, inquiry, traditional subject matter of life, Earth, and physical sciences, science and technology connections, science in personal and social perspectives, and the history and nature of science. Fundamental concepts that underlay each standard are included with information on developing student understanding of the content standards. A chart in the *National Standards* gives a comparison between traditional science education and the new vision of scientific literacy required for the modern world. The content standards encompass the following changes in emphases: 1) moving beyond only learning scientific facts and information to using inquiry processes, 2) understanding scientific concepts and inquiry abilities, 3) learning subject matter disciplines (geosciences) in the context of inquiry, technology, personal and social perspectives, and the history and nature of science, 4) connecting all aspects of science, (Earth systems science is a model in the geoscience of such integration), 5) studying a few fundamental concepts deeply, and 6) working with inquiry as a teaching approach, as an ability and as an idea about science to be learned. (NSES p. 113).

Transforming Undergraduate Education in Science, Mathematics, Engineering and Technology, (NRC/NAS) - The National Research Council/National Academy of Sciences has also published its study on what constitutes excellent undergraduate science education in *Transforming Undergraduate Education in Science, Mathematics, Engineering and Technology* (NRC/NAS/NRC 1999) The goals are stated as visions, including an expectation that the Academy's K-12 standards will be the basis for entry into higher education.

"Vision 1...Entry into higher education would include assessment of students' understanding of these subjects [Science, Mathematics, Engineering, and Technology,(SME&T)] that is based on the recommendations of the national K-12 standards." (NRC/NAS/, 1999 p.2.) The vision is further defined to include qualities of interest and application to society and human life in introductory courses. "Vision 2.

BSCS LEVELS OF SCIENTIFIC LITERACY

Nominal - students can recognize science terms related to natural phenomena but cannot provide scientifically valid explanations and have several misconceptions.

Functional- Students can define terms correctly but that ability is based on the memorization of information with little understanding.

Structural - Students can construct the appropriate explanations based on experiences and can discuss and explain concepts in their own terms.

Multidimensional- Students can apply the knowledge gained and skills developed to solve real problems that may require the integration of information from other disciplines within and outside of science.

Table 1. BSCS Levels of Scientific Literacy, adapted from BSCS, 1993.

SME&T would become an integral part of the curriculum for all undergraduate students through required introductory courses that engage all students in SME&T and their connections to society and the human condition." (NRC/NAS, 1999, p.3.)

Solid-Earth Sciences and Society (NRC/NAS) - The National Academy developed discipline study recommendations that confirm the qualities for science literacy and excellence in the geosciences. The recommendations are in accord with the Academy's *NSES*. The *Solid-Earth Sciences and Society* (NRC/NAS 1993) stated objectives are "..derived from the challenges facing society in which fundamental understanding of the solid-earth sciences plays a primary role" (p. v), including "understand the processes involved in the global Earth system, with particular attention to the linkages and interactions between its parts (geospheres)." The discipline study strongly recommends an Earth system science approach to the study of geosciences. It is described as "Boundaries between basic and applied solid-earth sciences are artificial. This process oriented integrated global approach should be incorporated into revised Earth science curricula in universities and schools." (p. vi)

The emphasis in this document is on understanding for use, abilities to make connections with the knowledge, (thinking skills) and attention to scientific processes and their applications. It reiterates the qualities called for in the *NSES* for knowledge, understanding and usefulness of science in society and personal life.

Developing Biological Literacy, A Guide To Developing Secondary And Post-Secondary Biology Curricula. (BSCS) - The Biological Sciences Curriculum Study (BSCS), developed a hierarchical model for levels of science learning from lowest to highest (Table 1). The lowest level of learning is based on recognition without knowledge. The next level involves memorization with little understanding. The next higher level involves ability to explain and discuss. The highest learning level focuses on the ability to apply knowledge, to make connections to new situations and other knowledge and to solve problems. (BSCS, 1993, p. 18-25). The BSCS categories of biological science learning is adapted in Table 1 for brevity and to encompass all sciences by dropping references to biology. The BSCS model provides a basis for developing a model for excellent geoscience education based on the *National Science Education Standards.*

NATIONAL PROFESSIONAL REPORTS

American Federation of Teachers (AFT) - In addition to the national scientific community documents describing criteria for excellent science education, national professional documents can be considered for alignment. The American Federation of Teachers (AFT) publishes reviews of state K-12 standards, including state science education standards. They have defined excellence in terms of challenging, clear, and disciplined ways of thinking and by what students should know and be able to do. "Each discipline represents a body of knowledge and a "disciplined" way of thinking.." "Standards..are meant to define what is essential for students to learn." "Standards must define..the.. content and skills students should learn." (AFT, 1998 p 1-3.)

The AFT is specific about the necessity to commingle content, skills and applications. "Skills isolated from content, and context or content items isolated from applications, are meaningless..." "it is imperative that the standards pursue process and application skills through the specific content of the subject areas." (AFT, p. 5)

The Fordham Foundation - The Fordham Foundation published a report on state science standards in March 1998, down-loaded from their web site, March 28, 2000. The criteria for excellence were stated generally and specifically. Referring to the criteria used for reviewing the 36 state's science standards, the report emphasized that state standards should be an indication of what students are to learn in science. "The first purpose for a set of standards....how the state answers the crucial question: "What do we expect teachers to teach and students to learn.." (Lerner, p. 12).

Lawrence Lerner, a physics professor at California State University Long Beach and author of the Fordham report, was specific about the problems related to listing facts as learning goals. "The great majority of standards take the form of a set of lists. (Lerner, p. 12.) "Lists have...a subtle disadvantage that is probably more serious for science than for other subject areas. The sciences have strong unifying theoretical structures at every level, from specific subdisciplines through general fields and entire disciplines to all of science...Unfortunately lists tend to obscure the profound importance of the theoretical structure of science.. More important, a list may be misinterpreted ..as encouragement to teach science as a simple list of facts." (Lerner, p.13.)

Lerner's, (Fordham Report) specific criteria for excellence was based on "* absence of error, *precision and accuracy, * the laboratory experience, * the importance of facility in mathematical language as well as English speech and writing, * the role of theory, its interaction with experiment, and its role in interpretation and prediction, * absence of things that should not appear in a good standard, such as pseudoscience, quackery, antiscience/antitechnology views, scientific ethnocentrism, and distorted science history." (Lerner, p. 13).

CRITERIA FOR DEFINING ACADEMIC EXCELLENCE

The pattern of criteria for excellence, although stated in different groupings in the above documents, are encompassed in the *National Science Education Standards.* The national documents cited provide criteria for developing a common model for excellent geoscience education. They call for combining understanding of the defined content, described in the NSES in eight categories of the content, (unifying concepts and processes, inquiry, traditional subject matter of life, Earth, and physical sciences, science and technology connections, science in personal and social perspectives, and the history and nature of science). They combine content knowledge and ability to use that knowledge in new situations, recognizing interconnections with other content knowledge and skills, abilities to think critically, using knowledge to solve problems (scientific, personal and social), and abilities to use their knowledge and skills to think in ways that enhance economic productivity in a quickly developing and changing technological world. A model that encompasses these criteria could therefore be a useful model for evaluating the attainment of excellence in geoscience curricula documents.

SYNTHESIS OF THE CRITERIA FOR EXCELLENCE

Returning to the BSCS hierarchical model for science achievement, it is evident that the highest BSCS levels encompass the criteria for excellent science education explicated by the national documents in this study. The framework provided by the BSCS highest levels of achievement can therefore, provide a structure for the synthesis of the criteria identified in the study. The adapted BSCS highest levels of learning are: Structural level- Students can construct the appropriate explanations based on experiences and can discuss and explain concepts in their own terms, and Multidemensional level- Students can apply the knowledge gained and skills developed to solve real problems that may require the integration of information from other disciplines within and outside of science. (BSCS, p. 18-25)

Included in these two highest levels of science learning achievement are 1)understanding defined content and 2) the ability to use those understandings. Understanding of the defined content knowledge in the *NSES* includes the eight content categories cited above. The ability to use the knowledge in new situations includes recognizing interconnections with other content knowledge and thinking abilities, also cited above.

A model of academic excellence for science education adapted for geoscience education emerges from the synthesis of the criteria identified in the national scientific documents and corroborated by national professional documents. All the qualities identified are incorporated in the Geosciences Academic Excellence Model, Table 2.

By meeting the Excellence Model criteria a geosciences learning document such as an undergraduate syllabus or program, or a school district curriculum, could be responsive to the criteria of excellence provided by the national scientific community.

USING MODEL FOR ANALYSIS OF ACADEMIC EXCELLENCE

The Geoscience Academic Excellence Model (Table 2) is a working model to evaluate excellence in undergraduate programs and courses and K-12 curricula. It is useful in light of geosciences inclusion in the reforms of K-16 science education. The Geoscience

GEOSCIENCE ACADEMIC EXCELLENCE MODEL

Criteria for Evaluation of Excellent
Geoscience Education Documents and Curricula

I. Opportunity for all students to learn:

1. scientific content knowledge

2. conceptual understanding of the content

3. ability to do (apply, and use the science knowledge)

4. covering all defined content areas

5. critical thinking skills, scientific thinking skills

II. Attainment at the highest structural and multidimensional levels:

1. students construct the appropriate explanations based on experiences and discuss and explain concepts in their own terms

2. students apply the knowledge gained and skills developed to solve real problems that may require the integration of information from other disciplines within and outside of science.

Table 2. Geoscience Academic Excellence Model

Academic Excellence Model tabulates the categories and criteria for academic excellence. Based on the model, it is possible to develop rubrics for grading the levels of excellence of curricula documents and of student achievement. Public development goes beyond the scope of this study. However, for useful comparisons, it may be sufficient to consider a "pass/fail" analysis if excellence is desirable in various geoscience standards, curricula and courses. A "fail" would be a useful formative assessment in the process toward attaining excellence. Specific deficiencies can be identified and strengthened. Discussion can be focused and more fully informed. Confidence in the excellence attained can be enhanced with reference to the Excellence Model.

FINDINGS

A model of criteria for academic excellence in the geosciences synthesizes the criteria for excellence derived from the studies of the National Research Council/National Academy of Sciences, corroborated by other national reports. By citing the qualities of high academic learning, academic excellence can be identified and agreed upon in discourse about good quality geoscience education. The Academic Excellence Model will be most useful as a working model for evaluation, a reference for comparison, and as a guide for reaching excellence in geosciences education efforts in course design, syllabi, program design, and assessment of student learning levels. The model can be used as a means of communication and discussion and as a guide as geoscience departments revise their own programs and support K-12 education. Assessment for accountability systems can also be enhanced by reference to the Academic Excellence Model.

Revisions in geoscience education K-16 can reference the academic excellence model as a guide to raising expectations to help achieve the two geoscience goals: 1) general geoscience literacy for personal and social decision making and public support of geoscience research, and 2) for strengthening depth of understanding for geoscience majors.

The geoscience academic community can reach consensus on the criteria of academic excellence as reflected in academic materials (standards, curricula, syllabi, texts, etc.) in order to assist each other and the public with the reforms for science education. Geosciences departments are encouraged to develop curriculum alignment with the criteria for excellence derived from the scientific and professional society studies, and to assist state and local K-12 science education policy in achieving the same level of excellence.

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“Man puts his hand to the flinty rock
and overturns mountains by the roots
He cuts out channels in the rocks,
and his eye sees every precious thing...
Whence then comes wisdom?
and where is the place of understanding?”

Book of Job
Chapter 28