Facilitating Scientific Thoughtfulness for Non-Science Majors

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ABSTRACT

Science is not about the collection of factual data, nor is it centrally concerned with the search for universal or even limited truth. "Fact" and "truth" are attributes commonly espoused by both scientist and non-scientist alike, yet they are actually ancillary to the purpose of the uniquely human endeavor known as science. Science is, at its core, both a mode of thought and a powerful, successful mechanism for the rational exploration of nature. Far too often, particularly at the undergraduate level, students are overwhelmed with the mass of factual data science has uncovered, and they are rarely or never exposed to the beautiful interconnectedness of modern science. The success of reductionist approaches to scientific questions coupled with exponential growth of scientific specialization has thrown up major barriers to the scientific education of non-science students. Ensuring that colleges and universities continue to produce students with a foundation in scientific literacy is fundamental to a greater public understanding of science, and ultimately, the long-term continuance of the scientific enterprise.

In the spring of 1997 the Honors Council at Indiana University Purdue University Fort Wayne (a regional campus of the Indiana and Purdue system of approximately ten thousand undergraduate students) called for proposals for ten upper-division pilot courses from throughout the university. In response to that call, an undergraduate seminar course based upon the theory and practice of scientific thought was developed. With enriching student thoughtfulness as an ultimate goal of this new course, six interrelated teaching tools were fused to create a challenging learning experience for non-science majors. Socratic seminars and open forums provide opportunities for student-driven dialog on issues of scientific thought, scientific truth, and the diverse controversies currently associated with modern scientific research. Critical evaluation essays provide a mechanism through which students can expand their thoughtfulness on these questions in a written format. Critical reasoning projects and numerical literacy puzzles are smaller, more directed, learning instruments through which students are asked to think both logically and creatively to solve specific problems. Individual and group projects afford students the opportunity to further expand their creative thoughtfulness. Together these pedagogical techniques form a dynamic and extremely flexible learning environment in which students are challenged to expand their personal thoughtfulness.

Keywords: Education – science; geology – teaching and curriculum.

The following description of the facilitation of scientific thoughtfulness does not employ the standard embedded citations typical of most journal articles. Rather, in consideration of style of presentation, manuscript length, and utility to the reader, two listings of useful references are included at the end of the offering. ***Suggested Topical Source Material*** presents a listing of technical and popular writings on the history, philosophy, and practice of science, while ***Suggested Pedagogical Source Material*** provides a number of professional publications dealing with many of the educational concepts discussed herein.

BACKGROUND AND RATIONALE

Designing and building a course intended to provide undergraduate students with an understanding and appreciation of scientific thought is a task not to be undertaken lightly. The fundamental questions to pose when considering implementation of such a course (as well as any other course one might design) include: what should the students learn and why it is significant they should learn it? The inclusion of science courses in a general-education curriculum is often explicitly or implicitly driven by the notion that all undergraduate students should have an appreciation of the "scientific method." Unquestionably, students should achieve some level of understanding of concepts such as facts and theories, hypotheses and conclusions, serendipity and parsimony. However, should these ideas form the core of the scientific learning experience for undergraduate students? Contrary to the numerous formal guidelines, strategic plans, and general-education programs in place at many colleges and universities, I am of the opinion that students' scientific education should not be focused on, nor end with, these broad-based and often ill-defined themes. Likewise, non-science students should have a learning experience that transcends fact-based learning. It is not enough to dictate that the educational goal is to ensure the proper identification of muscovite and microcline; rather, we must insist that in some way all of our students have richer, more meaningful, learning experiences.

The seminar class in scientific thought outlined in this offering has been designed to have one central educational purpose – to allow students an opportunity to expand, develop, and apply personal thoughtfulness. "Thoughtfulness" seems in some ways at least as nebulous an educational goal as instructing students

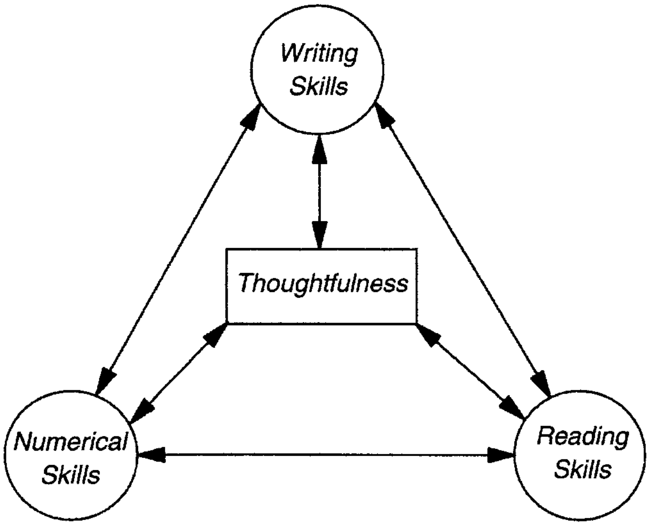

Figure 1. Thoughtfulness triangle illustrating interconnectedness among reading, writing, and numerical skills, and the central goal of thoughtfulness. This seminar class on scientific thought is designed to enact each of these aspects of thoughtfulness for the purpose of providing an educational environment wherein thought is fostered.

in the scientific method. However, there are a number of concrete steps that an instructor can take to foster student thoughtfulness, just as there are reliable techniques for assessing student progress in being thoughtful. Here I outline those I have found to be most useful. Only as a secondary objective to obtaining thoughtfulness can we hope for students to develop a life-long curiosity for, and appreciation of, science as a world-view.

At the core of this course is a desire to encourage students to think clearly and then to express those thoughts succinctly in both written and oral formats (Figure 1). It has been my experience that such a class, when successful, will prove difficult for students in that it provides new educational challenges in contexts they are unaccustomed to. Yet our course in thoughtfulness should not be difficult, at least not in the ways that courses in quantum physics, differential equations, or physical chemistry are perceived by students to be hard.

This seminar course should be accessible. Students spanning a wide range of educational backgrounds, experiences, and levels of sophistication must be able to participate and grow from a well designed class in scientific thought. Specifically, within such a course there will exist no finite body of information for students to master. There will be no problem sets to be overcome. As such, success in the course is determined by how the students grow in their individual and collective abilities to think critically, evaluate logically, and convey to others in a compelling way the results of their analysis. No matter what the students' chosen fields, developing the ability to think and communicate will prove far more beneficial than acquiring all the factual information they will obtain throughout their collegiate experience.

Course Structure

One of the greatest challenges facing an instructor who plans to implement a seminar course on scientific thought is the abandonment of many of the standard teaching techniques that we are all familiar with. This kind of course should be approached in terms of a joint exploration of knowledge and thought, rather than yet another opportunity for students to record and then recapitulate their professors' views, opinions, and biases. For that reason, selection of a room and meeting time are critical components in the ultimate success or failure of the seminar. Where at all practicable, a dedicated seminar room is preferable to a chalky, black-board-walled classroom or lecture hall. To encourage thoughtful discussion, a Tuesday/Thursday schedule with extended meeting times is preferable to a shorter Monday/Wednesday/Friday format. To create as informal an atmosphere as possible, a mid- to late-afternoon time slot is preferable to an early morning meeting time and, finally, the faculty member should both see and project himself as a group leader and as a facilitator but never as an instructor or teacher.

During the development of a course in scientific thought for non-scientists, many different outlines could be conceived, any of which might succeed in strengthening student thoughtfulness. I have chosen to divide my seminar into two independent but closely intertwined parts. Ideally, each section of the course should be sub-equal in duration over the term and in required student effort and output. The first portion of the seminar is dedicated to a broad-based overview of scientific thought; the second considers procedures and outcomes of the practice of modern science. Throughout both sections students have opportunities to learn about the histories and personalities of both well known and lesser-known scientists.

THE THEORY OF SCIENTIFIC THOUGHT

The first section of the course considers the general question, "What is science?" While no single answer can exist to a question so general, it is possible for students to begin to understand more clearly what it is that is meant by "science." It is critical for the seminar leader to realize – and to stress to the students – that this knowledge of science is as important and obtainable for those who are not science majors as it is for those who are training to be scientists.

There is an almost unlimited number of possible topics for examination in this first portion of the course. I have, however, selected two for detailed discussion in order to provide examples of the range and scope of questions available for consideration. It should be noted here and, more importantly, stressed to the students during the course, that none of these topics exists independently of the others. They all are closely related and together begin to answer the question of what is science.

Science and Truth – One of the most difficult concepts for students of science at all levels to grasp is the question of scientific truth. Is there truth in science, and if so, how can we set about finding it? Descartes, in his *Discourse on Method*, succinctly outlines a four-step plan for assuring one of finding the truth in a scientific inquiry. As such, class activities concerning Descartes' method can lead directly to consideration of deductive and inductive logic. Students need not become immersed in the details of formal logic in order to begin to grasp the way in which a highly structured, formal system of inquiry can be designed in such a way that the truth of a conclusion must follow from the truth of its premises.

By providing examples of reductionist approaches to scientific problems and the subsequent reconstruction then necessary for reaching a conclusion of broad interest, the instructor can illustrate how these centuries-old concepts are directly applied to modern fields such as molecular biology or particle physics. Sharp contrasts can be drawn between the deductive structure of pure mathematical logic and the strongly inductive character of most modern scientific analysis. Of course, that contrast then leads one to consider the incompleteness of formal systems.

Overviews of the impact of such works as those of Gödel, Tarski, and Turing on the efforts by Russell and Whitehead to establish a logically self-consistent mathematics in the *Principia Mathematica* will provide for our students both an example of the nature of scientific advances as well as insight into some of the fascinating personalities behind those changes. An interesting parallel is then constructed between the way in which those approaches to formal systems evolved and the ongoing transition from a fully deterministic and reductionist view of science (as has prevailed since the days of Newton) to a more indeterminate, perhaps largely stochastic, view as driven by recent advances in the study of complex systems, self-organization, and dynamical chaos.

Paradigms and Progress – Just as with truth, the concept of scientific progress is a complex and multifaceted topic for discussion. It is extremely tempting for students to consider only past scientific work in terms of our modern knowledge and perspective. Therefore, it is critically important for the seminar leader to present past theories and hypotheses in terms of the historical, cultural, and social fabric of their time. An obvious starting point for a discussion of scientific advance is Kuhn's influential *The Structure of Scientific Revolutions*. This seminal work forms a solid, yet controversial, foundation upon which to build a series of class dialogs on the ways in which science goes about its evolutionary changes.

Generally following the Kuhnian outline, the class should consider how scientists set about solving problems. Inasmuch as the detailed observation and recording of natural phenomena are central to most scientists' day-to-day activities, and are in large part what drew many to their career, students should come to appreciate how these puzzle-solving efforts lead to a broader and more precise understanding of the natural world. A sharp contrast could then be made between these normal activities of most scientists and the occasional extraordinary discovery that significantly alters the direction and tone of scientific thought. The leader can provide class activities that illustrate the far-reaching impact of such figures as Newton, Darwin, Curie, Poincare, Heisenberg, Einstein, and Mandelbrot among many others. Importantly, the goal of this kind of activity is not for the students to grasp fully the details of the work of these individuals, but rather to derive an understanding of how a major paradigm-shifting discovery ultimately alters the ways in which everyone, scientist and non-scientist alike, views the world. Interesting topics for consideration include the impact of these major shifts in the nature of scientific theory upon societal views of nature, religion, and mankind's place in the universe, as well as the temporal lag between publication of such revolutionary works in professional journals and the recognition of their significance by the general public.

Significant class time should be given to recent works such as Horgan's *The End of Science*. This particular tract, as well as other similar essays and books, suggests that the era of far-reaching scientific discovery, of major paradigm shifts in our understanding of nature, may be coming to a close. Careful comparison should be made between Horgan's characterization of scientific "diminishing returns" and Kuhn's views of the activities of a scientific discipline immediately prior to a major paradigm shift. Students should be challenged to ascertain which of these two views might most accurately represent the situation in modern science. Is Horgan's thesis flawed or valid? How would one go about finding out? Can the concept of the end of science be approached scientifically rather than in terms of a literary critique such as that conducted by Horgan? Does Horgan's observation of "ironic science," as practiced by many theoreticians, represent science at all? These and similar lines of discussion allow students to exercise their creative thoughtfulness toward a problem they may not have known existed. In the end, as with most of the material to be discussed in our course, it is not necessary to reach a conclusion to such questions, but rather the effort of evaluating them is the essential experiential goal.

The Practice of Science

The second section of this seminar course is designed to evaluate a wide range of current topics from the earth sciences. Importantly, throughout this portion of the course, students are to be encouraged to consider not only the issues discussed according to their own merits, but also to apply a new-found understanding of scientific thought to their analysis of these current scientific controversies. In this way, they take many of the tools acquired from the first portion of the course and apply them to their thoughtfulness when dealing with the content of the second part. The seminar leader should incorporate a mix of extremely topical issues with some of the more traditionally vexing debates. As such, class materials could be drawn from popularized accounts of scientific discovery, the science sections of major newspapers and periodicals, government policy statements, and on some occasions professional publications.

Specific choice of course materials should hinge upon the interest and experience of the instructor, as well as the backgrounds and interests of the students.

A wide-ranging, but surely incomplete, listing of interesting topics include the K-T boundary and the death of the dinosaurs; the past, present, or future occurrence of Martian life; global warming and associated atmospheric changes; the massive environmental problems of the nations of the former East Block; earthquake prediction; ice tectonics on Europa; and the role of climate in Hominid evolution. I would strongly encourage the seminar leader to clearly understand, and to then pass on explicitly to the students, the fact that there should be no "set in stone" list of topics to be covered in a given term. If the students find a particular issue or group of issues interesting, they should be let free to stay with them. Likewise, if the leader finds that a particular discussion has become stagnant, the group should then move on to a different topic. Since this form of curiosity-driven inquiry is fundamental to scientific discovery, it should serve also as the intellectual model for the conduct of this seminar class.

Again, it is critical that the seminar leader continually remind the students of the thoughts, ideas, and controversies they evaluated in the first portion of the course as they begin to grapple with the complexities of modern scientific debate. Just as the first portion of the course should not be presented solely in terms of the history or philosophy of science, the second portion of the course should not become simply a matter of fact or opinion. It is the goal of the course to encourage thoughtfulness, and central to the idea of being thoughtful is the continual comparing and contrasting of information and ideas gained from a previous discussion to those of the current discussion. While a sharp break in subject matter takes place between halves of the term (Robert Bakker and Francis Bacon are, after all, worlds apart), the underlying educational themes can be carried through the entire semester.

THE NATURE OF THE LEARNING PROCESS

In the proceeding I have provided a general outline of course materials and content; the question remains, however, in what actual activities will our students of thoughtfulness be engaged? In designing this course, I have drawn upon personal experiences from past classes as well as extensive discussions with professional educators and colleagues from a wide range of disciplines throughout the geological sciences. Within my version of this course, I have incorporated six different but linked activities to facilitate student thoughtfulness. These are Socratic seminars; open forums; critical reasoning projects; numerical literacy puzzles; critical evaluation essays; and written and oral reports of group and independent research (Table 1). It is not my purpose here to describe fully or explain the pedagogical benefits and drawbacks of each of these various techniques; rather, I hope to illustrate the ways in which each can be applied to this course. Certainly, other techniques might prove applicable and effective in encouraging student thoughtfulness, and this list of six is amenable to alteration or expansion to suit the strengths and preferences of the seminar leader.

Grading Structure Scientific Thought – Theory and Practice	
25%	Socratic Seminar Participation
25%	Critical Evaluation Essays
25%	Critical Reasoning and Numerical Literacy Projects [12.5%each]
25%	Research Projects [12.5% for both Group and Individual Projects]

Table 1. General outline of the grading structure of the course on scientific thought. In as much as some formal grading policy might be required by students or administration this structure has proven to be as workable as any other.

Socratic Seminars

Socratic questioning represents one of the oldest techniques of formal education. There are numerous variations on the Socratic theme in use in many different educational programs. For our course, Socratic seminars will form the cornerstone of our efforts to instill thoughtfulness.

> *Socratic seminars are inquisitive dialogs among students based upon a written text, followed by a period of personal reflection.*

Let us examine each of the parts of this definition in detail.

Dialog – Socratic seminars are formalized communication structures that take on the characteristics of civil dialogs. Importantly, Socratic seminars are not discussions, nor are they debates. This point is made most clear by consideration of the following goals: students should focus on understanding rather than on being understood; they should strive to grow from the experience of being thoughtful rather than to sway other participants to their point of view. As such, seminars are honest, open, candid, and factual conversations wherein students grapple with one or more difficult issues presented in the text. Thus, Socratic seminars are not about what is known *a priori*, but rather what the students and facilitator as a group of scholars can *learn*. This characteristic makes Socratic seminars an exceptional learning tool given the diverse backgrounds of students encountered in a class of non-scientists.

Students [and facilitator] – Socratic seminars are dialogs among the students, not between the students and the facilitator. In a successful seminar, the students begin to question each other, and, as such, the dialog centers on the interplay of their thoughts rather than on an intellectual exchange between the facilitator and the students (Figure 2). The role of the facilitator is first to choose a text that will stimulate meaningful, thoughtful interaction, second to initiate the dialog by posing an initial question for consideration, and third to keep the dialog focused on the text and ensure that all have a fair and free opportunity to participate. It is not the role of the facilitator to participate in the dialog! By that, I mean the facilitator should never give views, opinions, or analysis with

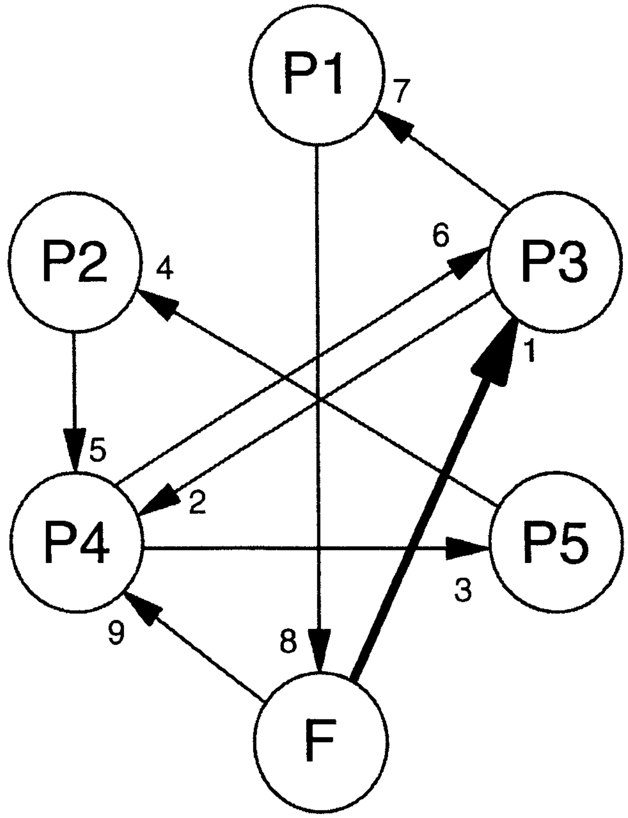

Figure 2. Conversation web of the first few minutes of a Socratic seminar. Numbered arrows indicate the progression of the dialog. The heavy arrow labeled 1 represents the posing of the initial question by the facilitator (F). Note that all participants (P1-P5) were actively engaged in the dialog and that communication was largely between participants and was not an exchange between the facilitator and individual participants. As the facilitator and the participants become more familiar with the Socratic method, the structure of the dialog should come to take on a pattern such as this.

regard to the text in hand or the questions posed during the course of the seminar.

The students are responsible for the success of the seminar. The educational benefit they derive from participation is directly proportional to the degree of their engagement in the dialog. Importantly, engagement need not always consist of verbal participation. One can only be thoughtful when one is thinking, and thinking and talking are not activities that one easily engages in at the same time. In short, the seminars are for, about, and by the students. The only goal is thoughtfulness, and the only desired outcome is intellectual growth.

Text – The basis of every seminar meeting is a written text, the choice of which is fundamental to the success of the experience. A good text should be brief but not necessarily short; it should be rich with ideas but not rambling; and it should be challenging while not incomprehensibly opaque. Because students should focus on the text as the source of their dialog, it should be physically presented to them in such a way as to facilitate its use. Specifically, it should be double-spaced, with wide margins for ease of annotating, and it should include line numbers (paragraph numbers for longer texts) to allow for reference during the dialog. For the seminar facilitator, selection of high-quality texts is as much a learning process as participating in the seminars is for the students. As such, if a particular text fails to stimulate thoughtful dialog, the facilitator is obligated to end the seminar and search out a more dynamic text for the next time. Failing to recognize that a text is not working, for whatever reason, is a much greater mistake than was its selection in the first place.

Second only in importance to the selection of the text is posing the first question of the seminar. The facilitator *must* realize that Socratic learning is not about finding the answer or reaching closure; rather, it is only about thoughtfully evaluating the questions raised during the dialog. The facilitator must choose with care the initial question for the group to consider. It should be specific, and yet open ended enough to lead the group to think about many issues. If the dialog slips too far afield, the facilitator should return focus to the text and the initial question; but, if the group shifts the dialog to a rich and thoughtful topic that is different than that which the initial question posed, the facilitator should not force the group to return to the initial "intended" topic. Good texts and good seminars will allow for consideration of a wide range of topics, many of which might not have been considered by the facilitator. Thus, the initial question starts the dialog; it never defines the dialog.

"Rules of the Game" – Socratic seminars are formal settings for civil dialog. Therefore, it is important to develop a set of ground rules that ensure that the experience is as inclusive as possible. It is the facilitator's job during a seminar to see that these rules are followed closely and that all have a fair opportunity to participate.

- Participants are to be polite and respectful of others.
- The text and personal experience are the only sources of information available for consideration. Participants cannot bring into the dialog the opinions of others or outside sources of information.
- The text should be referred to when needed during the dialog. A seminar is not a test of memory. Participants are not "learning a subject"; rather, they are aiming at developing an understanding of ideas and issues.
- It is okay to "pass" when asked to contribute during the seminar.
- Students cannot participate if they are not prepared. If they have not read the text, they are not prepared.
- Participants should be instructed not to stay confused; they should ask for clarification of issues or comments they do not understand.
- Participants must stick to the point and should make notes about ideas to which they want to return.
- Participants are not to raise hands; rather, they should take turns.

- Participants should speak loudly and clearly so that all can hear the ideas being considered.
- Participants should listen carefully.
- Participants are to talk to and question each other, not the facilitator. This is their learning experience.
- Participants are responsible for the success of the seminar.

If these rules are carefully observed, the seminar will be run smoothly and be a very effective tool for teaching thoughtfulness.

Reflection – Following the conclusion of each seminar there is a reflection period. This is not a time for continuing the dialog, nor is it an opportunity to summarize or synthesize points made during the dialog; rather, it is a time for considering the experience of participating in the dialog. The reflection is initiated by a second question posed by the moderator. Suggested questions for reflection include: What was it like to participate in a Socratic seminar? How was this seminar different from previous ones in the term? What did you find difficult? What aspect of participation came most naturally? How would you assess your level of participation and engagement in the dialog?

Importantly, the reflection is a time for everyone to share his or her experiences. It is the only time at which a student may not "pass." Each must say something regarding the reflection question. The reflection serves the double purpose of allowing students to be thoughtful not only about the text, but also about themselves. It is a chance for personal evaluation. Facilitators will likely be surprised at the candid and frank evaluations students will perform on themselves after a successful seminar. As such, the facilitator can draw upon the student responses to the reflection in order to evaluate the progress of the group in becoming more thoughtful.

In summary, Socratic seminars can be fascinating and highly charged learning experiences for the students and facilitator alike, but they require both effort and honesty.

Open Forums

Open forums are simplified – more free form – modes of group communication. Much like a Socratic seminar, open forums are focused on a text and are initiated by a question posed by the facilitator. However, in this case, the group leader may have a specific educational objective. The leader seeks to address one or more points and becomes significantly more engaged in the dialog than in a Socratic seminar. Open forums are best utilized after students have had several opportunities to participate in Socratic seminars. Those experiences will provide a foundation for civil dialog and an understanding of the thoughtful exchange of ideas. These settings are ideal opportunities for the leader to draw together themes or concepts from a number of past learning experiences and, on occasion, to present new material as the forum proceeds. In my experience, students enjoy the change of pace between a forum and a seminar. The occasional inclusion of this form of learning will serve to enhance participation and engagement if the leader finds the group dynamic is slipping. However, forums should not be viewed as a replacement for Socratic seminars, nor should students come to lean upon the higher level of interaction between the leader and the group during a forum. These dialogs add spice to student thoughtfulness; they are not, however, intended to be the main course.

Critical-Reasoning Projects

A central aspect of the practice of science is the critical examination of evidence, the development of a line of reasoning, and the establishment of a sound conclusion or interpretation based upon the information at hand. Additionally, these steps must be accomplished in writing and delivered with a high level of clarity and precision such that they will stand up to critical review. Critical-reasoning projects are small puzzles or problems upon which students are to hone their skills of analysis and written communication. The latter are acquired abilities, ones that professional scientists continually work at improving, and they are universally applicable to any career path a student might follow. I have applied critical-reasoning projects over a wide range of intermediate to advanced geology courses and have found them to be exceptionally powerful tools for forcing students to address individual problems in creative and thoughtful ways and then clearly communicate the results of their thinking in written form. They are a natural component of this course on scientific thought.

Critical-reasoning projects consist of two parts, an introductory statement followed by five responses (Table 2). The introductory statement serves as the "text" for the problem. It typically presents enough background material to allow for the project to be completed without major research into additional source material. Each project should, therefore, largely stand alone. The five responses to the introductory statement serve as the subject for the students' analysis. Students are to accept one of the responses as true or most correct and reject the other four. Importantly, it is not the selection of accept or reject that determines whether the student receives credit; rather, it is the written analysis of the decision to accept or reject that is important. Thus, each selection of accept or reject must be accompanied by a well written, logically reasoned argument supporting the student's decision. Each response should be limited to only a few sentences. In all, the students should not spend much more than an hour on any particular critical-reasoning exercise. As the seminar leader designs the individual projects, care should be taken to insure that only one answer is most correct or most likely. The analysis should not be trivial, nor should it be of such complexity or subtlety that the students are unable to address the problem adequately. It is the students' responsibility to find the best answer from among the ones given, explain why it is the best, and then describe why the others are less correct.

Student arguments must be well reasoned and based solely upon the problem itself. Unacceptable arguments include simply giving accept or reject answers

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Critical Reasoning Problem 1

Score ________

If you are not absolutely sure of the meaning of the words *assumption, observation, hypothesis, prediction,* and *conclusion,* look up their definitions. Based *only* on your understanding of the above words, the following statements are **conclusions**. ACCEPT or REJECT.

1. If deposition was influenced by extrabasinal forcing, such control must have been nearly random in both secular and spatial dimensions of water depth change.

2. Poisson attributes of stratigraphic durations and recurrences of these peritidal units suggest that they more likely record the inherently stochastic character of epicratonic sedimentary processes than any appreciable influence of rhythmic eustatic control.

3. Minor amounts of terrigenous silt and sand as either disseminated grains or discrete beds occur within shallower peritidal carbonate units.

4. This difference was likely related to enhanced rates of carbonate precipitation associated with photosynthesis and/or particulate trapping activities of cyanobacterial colonies.

5. At one extreme, we might presume that sedimentation was more or less continuous, albeit at rates well below those typical of low-latitude Holocene settings and that cessation of accumulation of one type of sediment was closely followed by initiation of another.

Table 2. Example of a critical-reasoning problem used in the scientific thought seminar. The purpose of the exercise is to allow students to evaluate the structure of writing even when the vocabulary, content, and context are extremely obscure. Students were encouraged to diagram the sentences such that unfamiliar words or phrases were given letter designations (that is, from #2, A and B suggest that C is more likely than D.) Statements were derived from one of the author's research publications, but similar statements could be drawn from any part of the professional literature.

with no logical supporting reasoning; reliance upon authority – "because that is what my Physics professor said"; or an unsupported assertion – "this can't be right because I know this other thing is right." Students should be allowed to discuss their answers to the problems with each other and with the leader, but the written responses must be the work of each individual, not a team effort. It must be clear that no credit should be given only for providing the "right" answer to the accept or reject portion of the problem. Rather, credit is only given for the analysis. Since the leader is constructing the problems, there will likely be one answer that is intended to be correct; however, students should and will at times disagree with the leader's choices. If the argument is well reasoned and convincing, the student should receive credit. However, the student can only receive credit for what is written on the page. It is not enough for the student to later plead, "Well, what I meant to say was...". Likewise, the leader must be prepared to mark as wrong a correct selection of accept or reject that is followed by either non-existent or poorly reasoned logic. That decision must be vigorously defended in the face of student opposition. Learning that just getting the "right" answer is not enough to receive credit is a very valuable experience for all students.

Ideally, students should be given a few days to work on the projects. The kind of thoughtful analysis stressed with this instrument requires time for students to digest the information presented as well as to evaluate the validity of their planned responses. While the actual writing of the response should not take much time, students should be given ample time to think through what they want to say. Less sophisticated versions of these kinds of projects are wonderful for in-class activities to be followed by an open forum dialog on the topic under consideration.

Numerical Literacy Puzzles

Numerical literacy puzzles are constructed in a manner similar to the critical-reasoning projects outlined above. Typically, they consist of a statement, relationship, or graph of numerical origin followed by statements on which the students are to work. The purpose of this particular learning instrument is to provide an opportunity for students to become conversant with the presentation, interpretation, and analysis of numerical data. Although in general these problems are similar to the critical-reasoning projects, there are some significant differences. Typically, numerical puzzles are constructed such that students do not assess the truth or validity of several statements but rather provide short answers to or analyses of a specific suite of questions relating to the introductory material or graph (Table 3). Some numerical literacy puzzles can be taken directly from published research papers. Detailed questions can be asked that require students to consider both the data and its method of presentation. Importantly, the exercises should go beyond being simply an exercise in reading a graph. Rather, they should stress analysis of the data. Other puzzles can be constructed by the leader to illustrate specific aspects of numerical analysis with which students are to become familiar. Examples of these types of puzzles I have used include analysis of Venn diagrams of categorical statements as well as exercises in pattern, symmetry, and form. Additionally, students can be asked to process given data in some way, through either graphing, elementary statistical analysis, or trend fitting. Again, it is important to state that these puzzles are designed to exercise student thoughtfulness, and as such there will often be no one "correct" answer, rather only more or less well reasoned analyses.

Critical Evaluation Essays

A fundamental component of this course is the demonstration of student thoughtfulness in written

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Numerical Literacy Problem 2

Score ________

In this problem, we will consider the concept of pattern. As with Bach's variations on Frederick's Theme, you are to develop five variations on the following pattern. There are eight possible "notes" and each variation must be at least eight "notes" long. You need not use each "note" in each variation; you are also allowed to repeat "notes." Beyond simply constructing each variation, you must provide a brief written explanation for the pattern that you chose. I want you to think seriously about this exercise and construct variations of which Johann would be proud!

Prince Carl the Annoying's Theme

A								
B								
C				X				
D			X				X	X
E	X	X						
F						X		
G								
H					X			

Table 3. Example of a numerical literacy puzzle drawing upon Douglas Hofstadter's description of an exchange between J.S. Bach and Frederick the Great as described in his book *Gödel, Escher, Bach: An Eternal Golden Braid.* The purpose of this exercise is to provide students with an opportunity to explore the notion of pattern within a structured framework. This particular exercise proved one of the students' favorites, and the quality of their written explanations for each chosen variation was most impressive.

form. Students must be challenged to write about their ideas and thoughts in a clear, concise, and well reasoned manner. These essays should be short, highly structured documents. Generally I have found that a simple five- to seven-paragraph format allows for presentation of enough information while not forcing students to struggle to fill space with words (Table 4). The goal of the essays is to improve student writing and not simply to make them write. An introductory paragraph, followed by three developmental paragraphs and a summary paragraph provides a flexible, yet sufficiently extended, format upon which students can develop their thoughts.

Critical-evaluation essays can be used two ways in a class on thoughtfulness. The first is to dovetail a critical-evaluation essay with a Socratic seminar or open forum. In this case, the leader asks the students to take one of the central questions discussed during the dialog and to expand their thoughts into an essay. In these cases, the student is allowed to bring in outside sources of information as long as they are well referenced. However, the essays are not research papers. The goal is for the students to present their own thoughts, not a summary of the thoughts of others.

Suggested Critical-Evaluation Essay Outline

- An introduction to the topic or subject of the text and the question which has been posed. One paragaph.
- A discussion of the question in light of your understanding of the text. Two or three paragraphs
- An optional brief discussion of outside sources or views with regard to the question. These must be fully documented if included. One paragraph.
- A summary of the conclusion you have drawn from the text. One paragraph.

Table 4. Suggested critical-evaluation essay outline describing the various parts of a well constructed essay. This outline provides both sufficient structure and flexibility to allow for the individual styles and various levels of writing experience of the diverse population of students likely encountered in a course for non-science majors.

The second way in which critical-evaluation essays can be used in our class on thoughtfulness is as a stand-alone learning device. In this case, a text or some other form of background material is presented to the students, and they are requested to address a single, significant question raised by the text. As such, the students must evaluate the question, assess what the text has to say about it, and then present their analysis of the question in terms of both the text and their own personal thoughts. In those cases where the leader wants to expose students to material that is either too lengthy, or perhaps too complexly reasoned to be well suited for a Socratic seminar or an open forum, this kind of critical-evaluation essay allows students the time to think through both the question and the text in great detail.

Students should be required to prepare their critical-evaluation essay with the aid of a word processor. Word processing is preferable to hand-written essays for several reasons. First, the student has available spell checking and grammatical aids, as well as in many cases a built in dictionary and thesaurus. Students should take advantage of these writing aids, so that their essays are error free and of the highest possible quality. Second, from the point of view of the leader, a word-processed essay is a much easier document to read and evaluate than is a hand-written essay. Thus, word processing is a benefit to both the student and the seminar leader.

Students should be encouraged to discuss their essays with classmates and the leader, but just as in the critical-reasoning problems, they should write their essays on their own. I have found that giving students a full week to complete an essay provides enough time for them to be thoughtful and yet a short enough period of time so that ideas and concepts raised in dialog are still fresh in their minds. Finally, I have strongly encouraged students at all levels to take advantage of university-provided services of peer review of student writing. These services allow students to have their essays critiqued by experienced

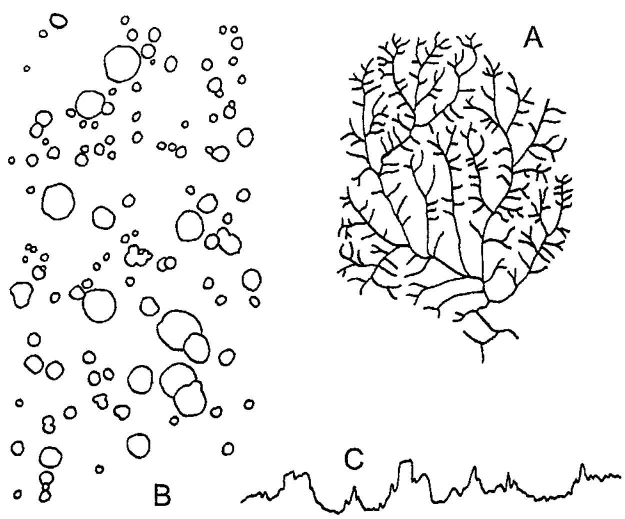

Figure 3. Three examples of morphological shapes used in the group projects. A – Insequent drainage network from a small mid-western watershed. B – Outline of a crater field from the Noachian highlands of the southern hemisphere of Mars. C – Vertical section through a stylolite. These features were chosen because they are both visually interesting and largely scale-independent.

writers in a non-judgmental environment, and I have noted a marked improvement in the essays of those students who have utilized such services.

Research Projects

Student thoughtfulness can transcend in-class activities and the occasional take-home writing assignments. One of the best procedures by which to allow students to develop long-term thoughtfulness is through participation in research projects. The specific details of how to implement research projects are largely up to the group leader's individual interests and tastes. In my course on thoughtfulness, I have devised two types of projects, the first a small-group project (teams of two or three) and the second an independent web-based research project.

Group Project – The purpose of the group project is to allow students to experience some of the highs and lows of conducting scientific research while not becoming bogged down in the details of data collection. The several groups of students are presented with a scale reproduction of a scientifically interesting morphological feature (Figure 3) that is some shape or set of shapes derived from the earth sciences. Students are not provided with information as to what the shape is, nor are they instructed to attempt to decipher the shape's origin. Rather, the purpose of the project is to develop a logical and complete research plan from which one could extract meaningful data about the shape. What is the size, shape, area, length, angular relations, or irregularity of the given feature? What measurements would best elucidate the geometry in question?

Students are to use their creativity to construct a research plan. The goal is not to determine the origin of any of the given shapes but rather for the students to come up with the most thoughtful and well reasoned set of measurements they would *like* to make on the shape. That is, the students will not make the measurements they design. A drawback of this approach is that the students do not get an opportunity to experience the frustration of having a well designed plan of research that proves to be unrealistic in its application and the attendant retooling of the research design such an experience requires. However, they are given an opportunity to think in creative and logical ways about how one would begin to approach a problem in shape analysis.

Student teams are to construct their research plan, write their ideas in abstract form, distribute them to their classmates, and then through oral presentation describe the measurements they have decided would be most meaningful. Thus, the presentation portion of the project takes on the form of a small, professional, scientific meeting with timed presentations and short periods for questions and answers after each talk. Materials for the projects should be distributed during the first one-third of the semester and presentations are to be made around mid-term. Thus, there will be several weeks for students to develop their research plans and prepare their presentations.

Individual Web-Based Research Project – During the second half of the term, each individual student is to select a current topic in the earth sciences on which to conduct a web-based research project. The group leader should oversee and assist in the selection of topics. An initial list of examples can be drawn from the suggested topics to be considered by the entire class during the second half of the term. Students should be required to select their topics soon after mid-term, after which they will have several weeks to search the World-Wide Web for sites that provide information regarding their chosen topic.

Reports derived from the student research will be presented in two parts. The first will consist of a formal written analysis of the topic researched. This will be a standard word-processed document, fully referenced, that might range in length from four to seven typewritten pages. The second portion will consist of an oral presentation to the class, for which a network-connected computer will be available. Each student will then be responsible for mixing his formal oral presentation with a cruise through the various web sites of interest concerning his chosen topic. During this presentation, the student will be serving as a sort of tour guide, explaining the features and details of the web sites he has found. Presentations will be on the order of fifteen minutes and will be conducted during the final-exam period of the class. Student presentations should be peer reviewed as to content, comprehensibility, clarity of presentation, and quality; the results of those reviews are then to make-up a significant portion of the grade for the project. The purpose of this is, of course, not to "wow" everyone with the web sites but rather to illustrate the range and scope of information available on-line, as well as to offer an analysis of the information presented in terms of the experience the students have gained during their study of the nature of scientific thought.

ASSESSMENT AND EVALUATION

Student progress towards being thoughtful is not readily amenable to quantification. That is not to say, however, that it is impossible to achieve meaningful assessment of progress in a course on scientific thought. Obviously, several of the teaching tools outlined above are structured in such a way that student success at being thoughtful is directly reflected in the "grade" given. Specifically, critical-reasoning projects and numerical literacy puzzles are direct measures of student thoughtfulness, and patterns or trends in student scores (as well as the general quality of their analyses) can be evaluated over the course of the term. Critical-evaluation essays as well as research projects result in written documents that are to be assessed in terms of the quality of the writing and the clarity of presented thought. Likewise, evaluations of group and individual presentations are to be done by the group leader, as well as the students' peers. Careful comparison between student-generated evaluation documents and those of the leader will provide interesting insights into student expectations. Are our students more or less demanding of themselves than are we in our role as their educators?

Perhaps the most difficult parts of this course for which to assess student progress are the Socratic seminars and open-forum dialogs. Several approaches to participant assessment can be used; however, in the classical Socratic form, notions of assessment, closure, and outcome-based evaluation are largely antithetical to the goal of thoughtfulness. That is not to say that some form of assessment is not appropriate. I have found that self and peer evaluation are solid techniques for assessing student participation and thoughtfulness. Likewise, the reflection question can be used as an informal assessment instrument. The only questions of critical importance to consider when evaluating student participation and growth from dialogs are: "Was the student prepared for the dialog?" and "Was the student engaged in the dialog?" If the answers are yes to both of those questions, then the students have been successful in their role as seminar participants.

Success in instilling student thoughtfulness is most directly recognized when the students request, and even at times demand, that dialogs continue or that additional source materials be provided. Perhaps the most rewarding experience for a group leader is to have a student ask to borrow the book from which an excerpt has been taken. At that point, the seminar leader knows that the students' interest and imagination have been captured, and that they are in the process of intellectual growth. Not every student will ask to read more on every subject; however, when students do request additional materials, that is a sure sign that the seminar course has achieved its goal of increasing student thoughtfulness.

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