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Research Article

The journey into inquiry land in Tennessee: How to get there from anywhere? Lessons learned over 25 years

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THE SOCIETY OF SIGMA GAMMA EPSILON

ABSTRACT

Driven by changes in the National Standards during the 1990s, inquiry became the pedagogical methodology of choice for K-12 sciences as a major paradigm shift. Inquiry was chosen because it realistically and accurately modeled how scientists conduct scientific studies. Scientific inquiry is itself a learning process, and early educational research suggested that students learned more efficiently through inquiry. However, inquiry was a difficult pedagogy for teachers to learn and for students to experience, as it appears chaotic and decentralized. K-12 Earth science in Tennessee was in need of revitalization, in terms of shifting to the new Earth systems curriculum and incorporating inquiry as the pedagogy of delivery. To tackle both problems in tandem, the authors collaborated with the Tennessee Department of Education, Tennessee Science Teachers Association, and Tennessee Earth Science Teachers (TEST) to develop a series of Earth science professional development opportunities in which inquiry was modeled as the pedagogical vehicle and content was organized into Earth systems. We provide an anecdotal before-and-after perspective that spans 25 years of experiential lessons the workshop leaders learned about the "journey into inquiry land" from any other pedagogy. These lessons, applicable to all sciences, serve as the cornerstone to teaching inquiry to new teachers, as well as to seasoned veteran teachers making the switch to the inquiry-driven classroom.

KEYWORDS

Inquiry, geoscience education, Tennessee, standards

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INTRODUCTION

Formal education traditionally has relied on a reductionist approach that condensed vast amounts of content into an organized progression of topics that purportedly covered the breadth of a topic to some reasonable depth, but also had a hierarchical organization that facilitated the learning process efficiently, primarily through notetaking. In this method the teacher is center stage, the owner of the information, and the controller of its dissemination. Students were viewed as sponges to passively, but efficiently, absorb (memorize) the knowledge. In actuality, this is not how the process of science unfolds. The traditional "chalk and talk" approach to science education may be efficient, but it is not realistic, and decades of research shows that it may not be the best learning method. For the past quarter century, inquiry, especially open-ended inquiry, has been replacing traditional teacher-centered education. Inquiry, as a pedagogy in science education, is defined as "the creation of a classroom where students are engaged in essentially open-ended, student-centered,

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hands-on activities" (Colburn, 2000, p. 42). According to the National Research Council (NRC, 1996; 2000) and American Association for the Advancement of Science (AAAS, 1993; 2013), real scientific inquiry requires that the learner (1) be engaged in scientifically oriented questioning, (2) give priority to evidence in responding to questions, (3) can formulate explanations from that evidence, (4) can connect explanations to scientific knowledge, and (5) finally, justify and communicate these explanations. While there has been a plethora of scientific research on the theory behind benefits, and challenges of inquiry, little has been written about the hurdles that new and seasoned teachers faced, and still face, in learning to implement inquiry as a central pedagogy (e.g., Furtak, 2006; Inoue and Buczynski, 2011), especially for the Earth sciences (e.g., Brown et al., 2006; Penuel and Gallagher, 2008; Gray, 2014; Newman et al., 2017; Fang, 2020; Harrell et al., 2023). Additionally, little has been written about the hurdles of developing Earth science teacher training opportunities that are modeled on inquiry. In this paper we offer a retrospective about the application of inquiry as a teaching methodology for K-12 Earth science education in Tennessee and how Tennessee teachers responded to this decentralized approach to teaching. Specifically, we focus on the encountered realities of adopting the inquiry approach, and realizations that were learned from providing professional development to teachers seeking to adopt this pedagogy in Tennessee, when inquiry pedagogy was initially introduced in the 1990s and 25 years later after implementation in Tennessee.

1990 – INQUIRY INTRODUCED AS THE NEW TEACHING PEDAGOGY

Science education was undergoing a complete revitalization during the late 1980s and 1990s, especially with the broad reforms, and subsequent problems of implementation and accountability of the No Child Left Behind Act (NCLB) of 2001 looming (e.g., NCLB, 2002; Goertz, 2005; Beatrice et al., 2009). Reading any of the Tennessee Science Framework Grades K-12 documents published since the early 1990s will demonstrate that the Earth sciences (astronomy, meteorology, oceanography, and geology), and especially geology, have been considered integral components of Tennessee education, at least on paper (e.g., Tennessee Department of Education, 1995; 2000; 2001; 2016). Earth science has been historically underrepresented in the curricula of a majority of schools in the State of Tennessee (e.g., Byerly and Gibson, 1999; data supplied by Tennessee Department of Education) and nationally (NSTA, 1988; Meyer and Armstrong, 1990; Rutherford and Algren, 1990; American Geological Institute, 1991; Ireton et al., 1996; NRC, 1996; Holbrook, 1997; Office of Educational Research and Improvement, 1997; Ridky, 1998; Shea, 1997). The National Science Education Standards (NRC, 1996) had given Earth science parity with biology, chemistry, and physics. It was recognized that geology, in particular, was an ideal vehicle for inquiry-based science education (e.g., Prather, 1996; Prather and Shrum, 1984) and the discipline of geology was used as the primary example of inquiry in *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000, p. 1–5).

Our discussions with the State of Tennessee science consultant and geoscience education leadership at the National Science Foundation led to the realization that there were three issues facing revitalizing Earth science education in Tennessee. First, Tennessee needed more teachers having up-to-date content training in the Earth sciences to meet state and national standards (there were only 21 schools teaching Earth science courses in 1995, data supplied by Tennessee Department of Education). Second, a plan was needed to encourage more Earth science courses to be offered in Tennessee schools, especially within rural west Tennessee. Third, new Earth science courses in Tennessee had to be inquiry-based using the Earth systems approach. In the pipeline teacher recruits to Earth science and the existing teacher workforce needed training to be versant in the new pedagogy of inquiry that was now expected to become central to all science education in Tennessee. It was clear that there was no quick fix to the dilemma.

Because of tight budgets and already full curricula for students, the most efficient way to introduce a new Earth science course into any Tennessee school at this time was to find an existing teacher, usually a biology or chemistry teacher, to offer a single geology or Earth science class as a special section in their school (often without remuneration) and then allow popularity with the students to ensure the course continued. Several hurdles existed including (1) finding teachers interested in adding Earth science to their curriculum, (2) finding school systems whose administration was receptive to the new course, at least on an experimental basis, (3) finding teachers with the content knowledge to teach Earth science, and (4) ensuring that these courses were based upon inquiry methods.

The 1995 revision of the Tennessee Science Framework for Grades K-12 was looming, so the authors worked closely with the Tennessee Department of Education science consultant to begin the task of revising and revitalizing Earth science education across Tennessee. One of the most important aspects of this collaboration was the establishment of the Tennessee Earth Science Teachers (TEST; see Gibson [2024A], this volume, for a history of TEST) to identify and organize practicing Earth science educators in Tennessee, recruiting new teachers to Earth science, and providing resources and training for inquiry as pedagogy. Thanks to support by the Tennessee Science Consultant, Dr. Linda K. Jordon, and the Tennessee State Department of Education, the primary responsibility for revising the benchmarks and indicators for this new framework was given to the Tennessee Earth Science Teachers (TEST) with advisors from higher education institutions across Tennessee. Their impact was almost immediate. In the revision of the 1995 Tennessee Science Framework, TEST redesigned the Earth science curriculum to focus more on a systems approach to Earth science and geology and incorporated opportunities for inquiry-based teaching into the standards (e.g., Byerly and Gibson, 1999; Hoffman and Barstow, 2007).

It was recognized that teachers for grades K-8 had science education needs that differed from those of secondary science teachers who focused on one or more specific disciplines (biology, chemistry, geology, etc.) and at a more advanced level of instruction. Additionally, most Earth science in Tennessee is delivered at the middle school level (grades 5–8). Another trend in Tennessee is that many of the topics in Earth science require a grade level maturity higher than the grade level in which Earth science is taught. As more science content is added to secondary level classrooms (e.g., expanded genetics concepts, technology, etc.), Earth science in Tennessee has tended to be moved to earlier grade levels and over-generalized (e.g., dinosaurs as an interest grabber; extreme weather). It can be argued that Earth science is better used as a capstone experience as it incorporates the principles of physics, chemistry, and biology that are not covered in classes until the secondary level. Earth science in Tennessee had become deemphasized.

The K-8 teacher's role is vital in preparing their students to become scientifically literate in these disciplines for three primary reasons. First, the likelihood of a student becoming interested in science often depends upon their earliest exposures to science education in the classroom. Good early experiences with science can lead to more favorable impressions of science, or of aspiring to become a scientist, especially for females. Alternatively, but equally important, is that negative experiences with science education at these grade levels can be the trigger that closes the door to favorable student perceptions and understanding of science for their future.

Second, the K-8 teacher will introduce their students to the basics of scientific inquiry (science as process) during the student's formative years. This period can have profound implications for later learning as it also molds student's attitudes toward learning science and shapes their "personal theories" that color their understanding of scientific processes, principles, and applications (e.g., Brown and Melear, 2006; Brown et al., 2006; Leonard et al., 2009). It is in these earliest years that students become aware of the world around them and develop a natural curiosity about how it works. K-8 teachers must be able to instill in their students an attitude that promotes science learning and develops self-motivation in the students. It should also be noted that at this age, most students show a keen interest in science topics, hence science is a natural motivator for cross-disciplinary learning (mathematics, writing, reading, etc.).

Third, these teachers will provide the initial Earth science content material that will form the foundation for all later learning. It is essential that this foundation be strong, with accurate information, and exemplify scientific inquiry as a "way of knowing" that is applicable to all phases of everyone's life (Moore, 1984; Chiappetta, 1997). The Earth sciences are much more integrative in that they use chemistry, physics, and biology (the base components of the "exact" sciences) to describe and explain the working Earth system. Additionally, the Earth sciences, essentially an interpretive science, adds the component of deep time to the sciences that is not present in chemistry and physics.

For these reasons, K-8 teachers in Tennessee needed to be proficient in a breadth of sciences (biology, chemistry, physics, Earth sciences) rather than be experts in one or two of the sciences (as secondary teachers are). K-8 science as it was promoted in The Benchmarks (AAAS, 1993), *Scope, sequence, and coordination of school science: Volume 1: The content core* (e.g., Tennessee Department of Education, 1995; 2016), and *The Content Core: A Guide for Curriculum Designers* (NSTA, 1993), emphasized inquiry-based education with the student as the center of the learning process, and the instructor as non-centered facilitator. It also emphasized learning using some form of the Learning Cycle. The science skills needed of this new generation of K-8 teachers was therefore different from that of the average science user because these teachers would be charged with the task of teaching the material to students who had a different cognitive development level than adults. These teachers were professionals who needed to have the content material presented to them in a form that would allow them to adapt it to accomplish all of these goals, either in their formal collegiate training or as part of professional development.

Once we recognized and acknowledged the professional needs of Earth science students in Tennessee, we could develop a training approach suitable for training those teachers (existing or new) who would teach Earth science to them as outlined in the competencies listed in the Tennessee Science Standards and consistent with the newly emerging national standards of content and pedagogy. These competencies had to be addressed in the science content courses required of students, as well as the elementary science methods course required in the teacher preparation program. What was needed were training opportunities for K-8 teachers that focused on inquiry as the vehicle using Tennessee Earth science content specifically.

We recognized that the circa 1990 Tennessee teaching work force consisted of two primary populations of teachers: those who have long established classroom skills developed upon their initial training and honed through years of practical experience within their personal teaching environments and the new work force teacher fresh out of college well imprinted with the supposed "newest" concepts and pedagogies geared to applying this college training. The seasoned vet had developed "tried and true" formulas for accomplishing educational goals that they were comfortable with and felt worked within their school and with their students using their existing (often limited) resources. There was inertial comfort in this approach because it is familiar, predictable, and they knew the results. It has always worked for them, so why change it? Thus, one impediment to introducing both inquiry pedagogy and Earth science content was that it was going to force the teacher out of their comfort zone and require them to take a risk in their teaching.

The solution to these impediments lay in the newly formulated National Standards, and by extension, the local state science frameworks that had determined that inquiry should be the foundational pedagogy to model because it results in more scientifically literate students. Inquiry, especially open-ended inquiry, was closer to what working scientists do in practice, so model it for the student. We might have suspected this somewhat obvious answer, but as lamented by many of our teachers, had the people that did the decreeing ever try it day-in and day-out in your school system with your students on your budget while being watchdogged by your administrator and questioned by your student's parents?

The second population of Tennessee teachers were the new recruits who most probably have already been immersed into the inquiry approach during their college training, have memorized the terminology, and been fed the theory long enough that it is their new paradigm. Under controlled settings and with lots of mentor support these teachers have used tentatively the inquiry pedagogy, but they lacked the "under fire" experience necessary to truly fathom the method. This group of teachers was in for a shock when they entered a school setting where inquiry was not the standard and they had to find a way to implement it; not in the more controlled college science education classroom atmosphere while surrounded by sympathetic peers, but in a real K-8 classroom full of less sympathetic students who are used to a different approach. They had to implement, in an operational sense, what had been idealistically planted into their professional psyche, but that they had little "real world" experience to draw upon and did not yet fully realize the numerous other day-to-day obstacles of being in an operational school system.

So, how do you make the transition from teacher-centered information broker to student-facilitator and information guide for the inquiring student? How do you motivate students to responsibly take charge of their own education by becoming inquiring discoverers? Beyond the theory and study of why inquiry is good for us, what do you need to know to implement inquiry, an inherently chaotic process, successfully? Below, we step outside of the theory and, through our experiential learning, outline the practical hurdles that we encountered and overcame during our 25-years of professional development programs and that our experience shows need to be overcome by anyone who implements inquiry.

We conducted a series of inquiry-based, hands-on workshops focused on basic geology, meteorology, and oceanography weaknesses in geoscience education in Tennessee. In 1990, 1991, 1992, 1993, and 1999 we offered iterations of Eisenhower Grant-funded GeoCamps which eventually evolved into a standardized basic prerequisite "boot camp" Geoscience Basics (GeoCamp I). GeoCamp I was followed by Surface Processes/Landform Evolution (GeoCamp II), and Earth History: Time & Life (GeoCamp III) (Byerly and Gibson, 1993; 1999). In 1997, we offered a modified version of the GeoCamps, funded through Educate America Act, Goals 2000 (called GeoTrek), and took teachers to study the Greater Yellowstone ecosystem (Byerly and Gibson, 1997). Later GeoTreks included international travel (e.g., Scotland, Belize). By the early 2000s, new GeoCamps had been developed which focused on meteorology, oceanography, and technological applications in the Earth sciences. All GeoCamps used open-ended inquiry as modeled instruction and emphasized local Earth science resources and local geology as content.

LESSONS LEARNED

The observations we offer are real obstacles encountered during the workshops we conducted for teacher training, from working with education students and Earth science majors at the college level, running programs for life-long learners, field testing with teachers for the American Geological Institute's Earth System Science in the Community and Investigating Earth Systems curricula, and discussions with teachers who have tried to make the switch (successfully and unsuccessfully). We offer some practical solutions to these issues that may help overcome them as they are encountered or to avoid them altogether by anticipating them.

Teacher as facilitator, not head-master instructor

We have found the most difficult impediment for teachers implementing inquiry is for them to step outside of center stage in the classroom… and stay there. We certainly found this to be a challenge for us while conducting training workshops, as we often felt the "teacher drive" to lecture, guide, push, and focus students and teachers to the goal we knew was at the end of the "instruction." In the traditional classroom, the teacher is the administrative head in control of the knowledge and its dissemination. There is a plan, and students are to follow the script. In inquiry, the teacher is a passive guide through most of the process. The students are the active participants and have ownership of the learning processes. They must make the process and product their own. An inquiry teacher spends much class time quietly walking around and observing, as if an interested tourist, whose presence alone offers enough authority to guarantee the students stay on task, but still allowing the students to own the timing and direction of investigative discovery.

When writing traditional lesson plans and outline notes (the ultimate in reductionist education), the progression of thought is determined for each student a priori. In reality, this approach is an attempt to herd students down a path that is believed to be discovery, but that ultimately arrives at a preconceived set of informational content, skill tasks, and critical thinking eureka moments. In the case of open-ended inquiry, however, the beginning point may be set (or more often arbitrarily prompted), but the path to the final product is not established by the instructor, nor will the outcome be the same for each student and each time. Each student, or working group, will follow a more or less disorganized, often seemingly random path, that is itself part of the discovery process, hopefully to lead up to the teacher's final list of desired outcomes. Often teachers found it difficult not to intervene when they thought that the inquiry process was heading in the wrong direction, did not proceed quickly enough, or did not seem organized and efficient. The natural urge was to step in, correct the situation, and get the students back on the right track. We had the same issues when we modeled the behavior during our GeoCamp professional development. It helped us to work as a team with one of us in the role of decentralized teacher and the other in the role of watchdog for the teacher to be sure that we did not slip into the non-inquiry behavior. Inquiry is about self-discovery, and like science itself, often appears disorganized and random for the teacher.

How do you keep from jumping into the center ring when the urge occurs? We have found that mobility is a simple, yet powerful tool. Get off center stage (usually the desk, podium at the front of the room, middle of a circle, front of a group on an outcrop, or some key control position that exudes top-down authority), and walk around your classroom constantly, briefly visiting with the students on "their turf." Keep walking, spending enough time with each student or group to offer some authoritative presence, effectively keeping them on task by showing that you are watching, keeping yourself informed of their progress and thought process, but transient enough not be the guiding presence. There is a natural tendency for the students to stop their process upon your approach and turn to ask you for an answer or to see if they are on the right track. This means they are seeking feedback, hopefully positive, and reinforcement; however, it does not mean that you have to take center stage again. Ask a question or two that will allow the students to evaluate their progress or to see another direction to pursue if they are heading down the wrong pathway. Once asked, they may attempt an answer. A positive response should be met with another question, a gesture showing your confidence in their progress in inquiry, or perhaps a query as to whether their other “scientist colleagues” in the class have suggestions for them (introducing the value of peer review). We found that a simple “sounds good so far” followed by simply walking on to the next group, thus signaling that “all is well” there, no need to stay and “fix” anything, and to “keep up the good work while I check on the progress of the others” did well.

Pay attention to recurring questions or pathways

In your decentralized role of outside observer, you will notice that most students and student groups will often encounter the same hurdles to their understanding, or come across some of the same eureka moment observations and interpretations, as part of their inquiry and discovery process. Watch for these as they become the milestones for your guided instruction. You can see their progress as they discover the intended outcomes and will gleam insight from the order or timing of their eureka moments. Sometimes the progression of the inquiry process will be the same for most everyone and may nearly always occur in a particular order; however, be especially vigilant for those alternate pathways as they occur. Once you see the patterns that are developing, you will be able to provide the right guiding question or comment to help push the inquiry process in a particular direction. Also, you may be able to predict what resources you will need to provide later as the inquiry unfolds.

For example, one of our in-the-field activities involved reconstructing ancient depositional environments using real geologic materials. The development of multiple working hypotheses is always encouraged in Earth sciences. We often encountered a situation where, based upon physical evidence that the student (or teacher) had observed already, they would attempt to conclude an environment or event, for example, sea level had dropped and the environments shifted from marine to terrestrial. Note that we are shifting from observations to interpretation (which was actually meant to be a hypothesis). All scientific hypotheses need to follow the scientific method and have predictability and testability. As the outside observers, we noted that the person doing this reasoning accepted this as a factual occurrence without critical evaluation (hypothesis testing), so we would ask them what types of sedimentary structures might they expect to see in the new environment that would support their interpretation (hypothesis). Usually, they would say something like mud cracks or raindrop impression in the rocks would be expected next. Here was a chance to provide positive feedback, but in a way that supported inquiry. Because the pattern had occurred in earlier iterations of the activity, we had previously amassed a set of samples that we could produce, only if the situation arose, that either reinforced or refuted their predicted hypothesis. After encouraging the students to vocalize (predict) the possible test possibilities (e.g., what sedimentary features that they could go look for would support or not support their predicted environmental interpretation), we would step in to provide that “newly discovered” specimen as the test of their hypothesis, as if they had gone looking for it and found it themselves (e.g., mud-cracked red sandstone, raindrop impressions in siltstone, terrestrial footprints, etc.). We found that this preparation from experience allowed us to infuse any necessary evidence, observations, specimens, or situations into the supposed non-predictability of inquiry without sacrificing open-ended inquiry itself. In other words, we learned to be prepared for eventualities in the process based upon repeated running of the inquiry process. We just needed to wait for the student’s inquiry path to reach the point where that information was now needed.

Model inquiry for the students

You will need to model the behavior that you are asking your students to undertake. Keep in mind the three H’s: *holism* (the whole cannot be understood by just learning the parts), *heuristic experience* (learning begins along empirical lines using rules of thumb to gain knowledge), and *hermeneutics* (science is an interpretive process based upon personal observation and knowledge). Do not expect them to be able to accomplish their own inquiry, much less accept it as a useful process to emulate, if you do not adopt it also. This is a matter of commitment and confidence that end-of-course goals will eventually be achieved while being flexible in the process pathway. Students learn by emulating good role models. One cannot successfully teach inquiry as a method by lecturing it. The Socratic method is useful in this regard. Avoid direct answers when a supportive question will achieve the same result. It is useful for students to see you be uncertain of an outcome or a process, but then go through the inquiry procedure as well. In other words, practice what you preach.

For example: Often, while examining sedimentary rock samples a student may become intrigued by the varied colors of the specimens and asks the teacher why a particular rock is colored red. The teacher's response could be one of the following depending upon what prior knowledge the student has: where are red earth materials found today, what do you recall about the process of weathering or, perhaps, why does a pocket knife or bicycle turn reddish in color when left outdoors? These leading questions could stimulate a dialog whereby the student recalls the processes involved in forming sedimentary rocks and might reach a conclusion where the student understands that iron in the sediment was either oxidized (weathered) at the source area and deposited as red sediment or that the sediment was subaerially exposed at the depositional site and the iron oxidized during deposition (by diagenesis).

Be patient; Don't watch the clock

Inquiring and discovering on one's own is not an efficient process to watch take place. It is, however, a realistic and reliable method to learn not only process of science, but also content. Inquiry is a form of experiential learning that becomes part of the student's life experiences, thus is more likely to be retained and used as a pattern for other endeavors. Most Earth science phenomena occurs locally and readily lends itself to this process as it is occurring in the student's world, so it is experiential in nature and personally relevant. So, although it does not seem efficient while it is occurring and the experience may be agonizing for the teacher, the long-term benefit results in more efficient learners, with greater self-confidence, more self-drive to investigate, and more experience to draw upon.

Postdiction in inquiry is prediction in practice

How does one know what resources students will need if their pathway isn't orchestrated? As illustrated by the previous geologic examples, this is one of the more challenging aspects of inquiry and to becoming a master teacher-facilitator. When designing the activities, a list of materials must be made and there should be a general idea of the timing of events, but this list is only a beginning list to get the inquiry moving. Inquiry is not predictable, but it is postdictable. A prepared facilitator needs to constantly be building classroom resources, manipulatives, and means of information access, so that when students reach a stage where they do need something that only a teacher can provide (some hands-on resource or access to information), one can be ready to facilitate their acquisition of that resource. Facilitators remain outside of center stage, but are more like "Johnny on the Spot" to keep things running smoothly, making efficient use of time, and not serve as dead ends.

Understand up front, it takes time to develop the resources to be an effective facilitator. The activity will constantly evolve and rarely become static. This means that one must learn what resources are needed to be prepared for the students when they need them. How can such needs be predicted when one did not design the entire process and cannot be sure of the pathway of discovery the students will take? You can't! Only repeated trials will supply this information. In this sense the teacher becomes not only a model of inquiry, but becomes a "learner" living the experience at the same time as their students. It also gives the teacher a better understanding of some of the obstacles the students are facing, from their perspective. Just as an effective teacher encourages students to keep a journal, it is useful for the teacher to jot notes in a journal about materials that are asked for (so they can be kept on hand), information needed (so that access can be provided), and typical inquiry pathways that seem to reoccur with student groups. In this way one can partially anticipate needs, but more importantly, be prepared to obtain what students need to facilitate their progress.

Versatility is a side benefit of the experiential development of one's resources

As inquiry activities are rerun and as on-site resources build, one will find that they are more confident in their role as facilitator (because of greater preparedness). Stress of being caught off-guard and unprepared will be reduced and the students will also see that they can accomplish inquiry successfully with them in charge and the teacher as their support. As we have run our inquiry activities, we have noticed that, over time, certain somewhat predictable directions of inquiry emerge more often than others. We keep resources on hand, out of sight, so that we can provide them at the time needed (which is never at the same time for each time the activity runs or at the same time in an activity for each group), reduce the amount of wasted time finding resources, and realistically model the process of science.

There is a certain amount of confidence building students obtain when they have control over the progress of their inquiry and have what appears to be authority to request information and supplies upon demand (rather than the "MacGyver approach" of being creative with whatever is on the table).

For example: In one activity used at the University of Tennessee at Martin Coon Creek Science Center for students and for teacher professional development we use an open-ended inquiry approach in which participants are divided into "research groups" and each group has a stratigraphic sequence of rocks to describe, identify, and reconstruct the history of the outcrop. This activity is assigned far enough into the course that the participants have already covered the numerous sea-level changes and orogenies throughout the Phanerozoic Eon in North America and the methods of determining geologic time, so one of the prompted questions the instructor gives is "which sea level sequence and geologic orogeny produced your package of rocks?" To answer this, the participant needs to know (a) where the rock sequence was collected (given information) and (b) the geologic age of the rocks (unknown at the beginning of the activity). When the participant asks what the age of their sequence is, the instructor asks in return, "How do you determine age of geologic materials?" Participants generally respond with "fossils" or "radiometric dating" (notice these are just nouns, not process answers, so the answer is not complete, but is their way of offering a half-hearted hypothesis). At this point the teacher/facilitator pulls a business card out of a pocket for a fictitious company called "Acme Geochronology Associates" which also has a list of fossils with geologic ranges (if the students responded with "fossils") or the results of radiometric testing (usually in the form of percent parent remaining or atoms of parent remaining so the students do the final calculations) on the back of the business card.

The participants, having arrived at the next needed information, were prompted with the necessary results at the time they requested. Notice that there is enough variability in the process that allow different groups to approach the same problem in slightly different ways, all realistic to geological inquiry. Notice that the participants then integrated previous knowledge into their next step. And finally, notice that the teacher never gave an answer, only facilitated the next step, and reinforced the student's progress simultaneously.

Inquiry is not the only method

Inquiry is one of many teaching styles, but certainly not the only one. The National Standards advocates using inquiry as the primary vehicle for education, but there is a place for other approaches, even traditional "chalk and talk." State frameworks adopted the inquiry philosophy and mandated inquiry as part of educational reform. Our experience in teacher training shows that many teachers mistakenly assume that they are being asked to wholesale shift to inquiry and use it exclusively over other more traditional methods. This is not the case, and there are many instances in which more traditional teacher-centered instruction will be the most efficient and produce the best results. It is necessary for you to determine which situations should remain teacher-centered and how to blend the approaches for a smooth transition from one arena to the next. This may not be predictable; rather you will find that you will experiment with different combinations of inquiry and non-inquiry for several teaching cycles before finding the right mix that works in your setting. One of the best uses of traditional lecture is at the end of an inquiry session when the teacher wants to (1) reiterate and reinforce what content knowledge was used in the activity, (2) introduce content knowledge that was not discovered during the inquiry activity, but still needs to be mastered, (3) to set the stage for the next step in inquiry, and to (4) finally reestablish the beneficial organization and orderly attention that a traditional teacher-centered classroom offers (a sort of "reset moment").

There is no magic formula for transition

Adopting new teaching approaches can be time consuming, initially resource expensive, and often a personally challenging task, but it does work. Of course, we all look for professional development opportunities and resources that will make this transition run smoothly and quickly; however, it is the nature of inquiry not to behave in these norms! Why should we expect the transition to be so organized if the actual inquiry method itself is not a rigid formula?

Take advantage of holistic nature of Earth science

The thin ranks of trained Earth science teachers, especially in Tennessee, necessitates recruitment of science teachers teaching other disciplines. While this is seen as a pitfall, it is also an opportunity to take advantage of a fundamental strength of Earth science. Earth science is the science pertaining to all aspects of the Earth, hence is holistic by nature. As noted above, it is an ideal "capstone" science in that backgrounds of the students can be varied, and that variation is raw material for their participating in the inquiry. This same characteristic holds true for teachers as well. Your students take other subjects either from you or other teachers. The process of investigation does not have to stop at your door. Science works in collaborative teams and so should you. Team with other teachers to carry over your activities in their classrooms by finding ways to reinforce one another's efforts. These do not need science classrooms. History, especially, is the result of Earth science impacting people through time (e.g., severe droughts and hurricanes that affected the settlement of Virginia in the late 1500s, eruptions of Santorini and Vesuvius, etc.).

Inquiry and holism require constant communication and reflection among the participants and some degree of orchestration ahead of time, but be careful not to reverse the inquiry atmosphere. Collaboration is more than sharing resources and coordinating outcomes. It is about reinforcing each other and demonstrating relevance of the content outside of the classroom setting in which that content is the primary resident. Interdisciplinary collaboration also affords the opportunity for teachers to become "active learners" as well as facilitators.

For example, we offered a teacher development program entitled, Thematic Earth Science for Tennessee Teachers, which was funded through the Tennessee Center of Excellence in Science and Mathematics Education (CESME) at UT Martin. The goals of the professional development included linking Earth science teachers and teachers from disciplines that appeared far removed from science to develop collaborative and complementary activities. One teacher in Knoxville linked with an English teacher to do a unit on caves and groundwater (Bailey et al., 1999). The students studied the formation of caves and groundwater quality in science class that included a field trip to a cave. Students then read and wrote poetry about caves in English class. Many of the English students were not enrolled in the Earth science class, but became exposed to the science through English. There was mutual benefit for both student groups as each group became "teachers" by sharing their new knowledge. For example, the science students were given a new medium (poetry) to couch their knowledge of caves, and a new and more creative way of demonstrating their mastery of content than standardized testing.

Use a field setting for basic inquiry skills

The relevancy of Earth science in making observations in the "every day" environment is obvious (Holbrook, 1997). Field experiences can be defined as extended field trips off campus, just outside of the classroom, or even virtual ones using the internet. Scientists routinely talk about getting into the field to study, which is another way of saying go where the subject is and get out of the black box. Nearly any experience that is not contrived and canned can be considered "field." Encourage students to find real world examples of all Earth science processes. The newspaper or television/internet news offers daily examples of Earth science topics and their constant change and occurrence underscores the importance of the topic to students. Building stones and aggregates occur and are used widely and are encountered often. Skillful scientific observation required practice. In the Earth sciences, observation occurs wherever you are, at any time, and in any situation.

Use field trip experiences as much as possible

Not only do field trips serve as wonderful platforms for student inquiry, but adventurous trips for educators also provide opportunities for recruitment of Earth science teachers and for instilling the powers of inquiry. They demonstrate the "real world" nature of their inquiry. Most of all, they are just fun and a change of pace from regimented education. Field trips contain impromptu opportunities (sometimes called "teachable moments") that the inquiry teacher learns to rely on, and on which to base much of their learning experience for later use. A field excursion can assist in learning to be flexible and making the most use of resources in the community.

Recap and wrap-up for the students

Inquiry activities need closure for reinforcement. As noted above, this may be the appropriate time for the teacher to take center stage again. At the end of each inquiry activity, summarize for all what was accomplished. Draw their attention to the method of science they used and then tally the results for all to share. Often there will be surprises, as there are all scientific inquiry, that are teachable moments to take advantage of. Even the "mistakes" and "tangents" are useful in this regard, especially as these mistakes may provide useful information for later inquiry. What about those content or process areas that you, as a teacher, know the student's needs, but somehow did not get addressed during the inquiry activity? Traditional lecture delivery, or an appropriate summary handout for homework, to tie-up loose ends is useful here to efficiently add this material, thus finishing all objectives and building upon the student's experiences. It may also provide an opportunity for a more even-handed grading activity that provides positive assessment feedback.

The importance of having appropriate resources

Earlier we discussed that resources would continue to build the more inquiry activities are utilized. However, one should not expect to be fully prepared the first few times of running inquiry activities. Shifting to inquiry can be fortified by adopting existing inquiry-designed curricula (e.g., Earth System Science in the Community [EarthComm for grade 9–12] and Investigating Earth Systems [for grades 5–8], developed by the American Geological Institute, were 1990s examples). Also, connections should be sought with local resources (college, industry, commercial, geoscience education societies, etc.) that can provide materials and expertise. Not all such resources are tangibles. Intellectual and creative resources are useful. Invited contacts from the community can often offer inquiry activities for students to work on or to help one design "issues" for a class to investigate. As a relationship with these intellectual resources builds, it may soon be realized that modeling real world applications of science is occurring, and the group effort nature of science is being demonstrated.

One must be willing to stay current

Science is about change and new knowledge, even in the Earth sciences where the focus is on history. Have the courage to put away "old" methods (activities, etc.), "outdated" concepts, "comfortable" pet topics and approaches to explore new directions. Many inquiry activities will be experimental and there is no guaranteed complete success at the beginning. This is okay and is a demonstration of the scientific method and progress.

Not every activity is going to work; do not be afraid to fail at first

Some inquiry leads to greater understanding than others. All inquiry is educational. Eventually a repertoire of useful inquiry activity favorites will be developed along with additional activities to fall back on when the need arises. Inquiry does not mean changing to a total chaotic teaching approach, but rather development of a new toolbox of activities that can be pulled and used when needed.

As we mentioned earlier, inquiry activities must be run several times before they are honed to optimum use. Buying into inquiry and new ways of teaching requires more preparation time initially than teaching by lecturing, which generally gives the teacher the feeling of classroom control. A good practice is to design and evaluate a curriculum by developing concept maps and rubrics in conjunction with the state science standards, rather than course outlines. Map these out in detail deciding what objectives are mandatory and what objectives are less important, but desirable. Use concept maps to map how a particular inquiry activity progressed as it unfolded. Mark potential pitfalls and areas of divergence for later reference.

Choose those objectives and activities to tackle first that can implemented successfully

Select inquiry activities that can be evenly spread throughout a curriculum so that different learning preferences are addressed and there are opportunities for reflection between activities. Once these activities are well established and smoothly running, identify and implement others to complement existing inquiry components. Keep in mind that the National Standards and Tennessee State Standards do not advocate all instruction as inquiry. Total conversion is not the goal. However, a wise philosophy is to eventually develop inquiry approaches to all curriculum components possible, so that one can have flexibility as a teacher when balancing inquiry pedagogy with traditional teacher-centered instruction.

Become part of a support system for the teachers willing to use inquiry

Higher education (not necessarily a good model for inquiry) should mentor with pre-collegiate educators. However, unless geoscience departments have faculty devoted to geoscience education, this is not likely to happen—historically tenure and promotion do not give very high rating to this type of activity; however, this trend has been changing in recent years as more and more universities are adding geoscience education positions. Contact and talk to teachers that have implemented inquiry and to graduates who participated in inquiry. Ask them questions such as "what were the most difficult aspects for you," "how did you overcome these," and "what was the most effective aid for you."

Student feedback

Student journals offer great potential for feedback (formative or summative assessment) on the effectiveness of an inquiry activity and allows them to vent frustrations with the process. Students should be encouraged to be candid with their comments and appraisal of activities. The ratings of students should be compared with one's own rating. Teacher in-service sessions can also afford opportunities to involve peers in activity evaluation, especially "new" activities. Rubrics for designing and evaluating activities should involve student input and considered integral to inquiry. Again, the goal is to encourage the student to be a part of the entire process and feel some degree of ownership.

Professional development opportunities.

Teachers should be life-long learners personally and professionally. Inquiry contains elements of both content and pedagogy. All school systems offer professional development. Use them regularly, including presenting your experiences as well as sitting-in on what others have done. You have experiences that others need to hear.

25 YEARS LATER: TENNESSEE EARTH SCIENCE INQUIRY PROGRESS 2024 SUMMARY

The itemized suggestions above were formulated by the year 2000 and incorporated into all of the Earth science workshops we ran for the next 25 years. We included these experiential tips as part of TEST programs and annual professional development at the annual Tennessee Science Teachers Association workshops and teacher sessions. These tips are also central to the mission and programing of the University of Tennessee at Martin Coon Creek Science Center (Gibson, 2024B). How have they stood-up over time?

Educational paradigm shifting is an evolutionary process that is best evaluated historically. It is also important to realize that education in general is continually evolving and paradigm shifts come and go. Inquiry was not a "flash in the pan" pedagogy that was tried, failed, and then discarded. It has remained the centerpiece of sound education. Yes, it did take time for those students who were introduced to the paradigm of learning through inquiry to work their way up through the educational system. As with most new procedures, there was a lag time where the benefits were not visible as the population of participants in the process increased. Inquiry has stood the test of time and is now the cornerstone of not only K-12, but also collegiate education.

Over the years of working with Tennessee teachers to improve K-12 Earth science education in Tennessee, the authors experienced many positive outcomes and many negative outcomes. We have seen a decided improvement in the incorporation of Earth science into the science curricula in Tennessee, mostly by infusing it into biology, physics, and chemistry at the secondary level (e.g., Gibson and Byerly, 2018). Most Earth science exposure has continued to shift lower in the curriculum to fifth-grade level in the newest state standards (Tennessee Department of Education, 2016). However, inquiry methods, especially open-ended inquiry, are now commonplace in Tennessee at all grade levels.

SUMMARY

The paradigm shift to inquiry-based learning/teaching was not necessarily easy for teachers of the Earth sciences in Tennessee. Along our 25-year journey to train Tennessee Earth science teachers in inquiry, however, we recognized certain attributes that we needed to hone within ourselves, and that we needed to instill in our participants. So, in addition to the practical considerations outlined above regarding implementation inquiry into Earth science education, we summarize with the personal encouragements that are also important to successfully implementing Earth science inquiry, or any educational paradigm shift, into your teaching:

- **Courage:**
  Be willing to take chances with something new and out of one's comfort zone.
- **Patience:**
  Be patient with students as they experience the new method.
- **Persistence:**
  Do not panic when activities do not go well at first and do not revert back to the "old ways."
- **Check yourself:**
  Step out of the center ring and let the students guide the progress of the activity.
- **Be resourceful:**
  Develop your "Johnny on the Spot" materials as time passes.
- **Be flexible:**
  Allow student creativity to direct; you follow with

support.

- **Get out of the box:**
  When possible, use field-oriented activities.
- **Community resources:**
  Gear activities to be relevant to the community ("place-based") and make good use of the resources available in the community.
- **Stay current:**
  Take advantage of professional development opportunities – content and pedagogy.

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