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Contextualizing the Relationship Between Nature of Scientific Knowledge and Scientific Inquiry

Implications for Curriculum and Classroom Practice

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Abstract
How nature of scientific knowledge (NOSK) or nature of science (NOS) and scientific inquiry (SI) are contextualized, or related to each other, significantly impacts both curriculum and classroom practice, specifically with respect to the teaching and learning of NOSK. NOS and NOSK are considered synonymous here, with NOSK more accurately conveying the meaning of the construct. Three US-based science education reform documents are used to illustrate the aforementioned impact. The USA has had three major reform documents released over a period of 20 years. The *Benchmarks for Science Literacy* was the first in 1993, followed by the *National Science Education Standards* (NSES) in 1996, and the newest, the *Next Generation Science Standards* (NGSS), was released in 2013. NOS or NOSK was strongly emphasized and given a prominent position in the first two, while the NGSS has marginalized the construct. It is categorized as a set of connections (with no specific standards or performance expectations) that can be made to some of the *Science Practices* or *Crosscutting Ideas*. However, a careful conceptual analysis of how the NGSS positions NOSK/NOS relative to the previous reform documents reveals a complex situation related to how NOSK/NOS is contextualized and apparent assumptions about how NOSK/NOS is best taught and learned. A historical review of how NOSK/NOS is contextualized reveals a longstanding confusion concerning the relationship between NOSK/NOS and SI as well as about how the reform documents seem to assume how it can be best taught to students. The assumptions often run contrary to the empirical research on the teaching and learning of NOSK as well as call into question the ability of the NGSS to promote the perennial science education goal of scientific literacy.

1 Introduction

The relationship and differences between nature of scientific knowledge (NOSK) and scientific inquiry (SI) are often discussed and confused within existing literature (Lederman and Lederman

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2014). NOSK, as opposed to the more popular phrase of nature of science (NOS), is used here to be more consistent with the original meaning of the construct (Lederman 2007). Nature of scientific knowledge was the original phrase used to describe the characteristics of scientific knowledge, as necessarily derived from the scientific inquiry process through which the knowledge was developed (SI). In recent years, Nature of Scientific Inquiry (NOSI) has also been emphasized and this refers to knowledge about SI. During the early 1970s, the phrase "nature of scientific knowledge" was reduced to "nature of science" (Lederman 2007). It is speculated that this change in phrasing became the root cause of the continued, to this day, conflation of NOS and SI. Hence, the label of NOSK is used here to more accurately communicate what is meant by NOS. NOSK and NOS have always been synonymous and refer to the characteristics of scientific knowledge, which are intimately related to, but distinct from, how the knowledge is developed (i.e., SI). The change in phrasing here is not meant to muddy the waters. Rather, it is meant to be more accurate in communicating the meaning of the construct historically referred to as NOS.

NOSK and SI are central to reform documents throughout the world, and the focus here is on how the contextualization of these constructs has significant implications for teaching practices and curricula, specifically with respect to SI. It is important to note that "contextualization" refers to how NOSK and SI are related to each other, not how either is related to subject matter knowledge in standards. That is, is NOSK considered to be a subset of SI or is SI considered to be a subset of NOSK? It is also important to note that the *Next Generation Science* (NGSS) is not a mandatory national curriculum. It is just a guide for curriculum and instruction. This further exacerbates the problem created by the contextualization of NOSK that is discussed throughout this article. As discussed later, the NGSS does not include NOSK in any of its performance expectations, which marginalizes its importance since understandings are not expected to be assessed and make it less likely for teachers to explicitly address NOSK.

The NGSS from the USA is simply used here as a concrete illustration of the problem. It is certainly not the only reform document of importance throughout the world, but it is focused upon here because of its recent release and international influence. Additionally, the NGSS, when compared to previous USA reform documents, clearly illustrates the changing contextualization of NOSK and SI and how NOSK has been marginalized in a manner that is inconsistent with the empirical literature on the teaching of NOSK. Before discussing the role of NOSK in the NGSS and in previous reform documents, a historical perspective of the emergence of NOSK as an important educational outcome, prior to recent reform documents, is important to consider. It is important to note that there is currently much discussion about the specific components of NOSK (Erduran and Dagher 2014; Lederman 2007). The focus here is not to dwell on developing a definitive definition of NOSK. Rather, of importance here is how NOSK and SI are contextualized and the implications of this relationship for curricula and classroom practices.

Following is a discussion of how NOSK and SI became viewed as critical outcomes of science education. This history culminates in how they are defined in the NGSS. This historical account is critical to our understanding of how NGSS currently views NOSK and SI. There is no attempt to definitively define NOSK or SI, but rather to explicate how the NGSS defines NOSK and SI.

2 The Roots of Nature of Scientific Knowledge As an Important Outcome in Science Education

Although the construct of NOSK was first discussed as early as 1907 (Central Association of Science and Mathematics Teachers 1907), research on understandings of the construct was not pursued in earnest until the late 1950s (Mead and Metraux 1957). Research in the area increased exponentially since the 1960s to the present, following the seminal work of Cooley and Klopfer (1963). There is no need to review the plethora of research concerning teachers' and students' understandings of NOSK, given the purpose of the present discussion, but for those who are interested, comprehensive reviews of this literature can be found in Lederman (2007) and Lederman and Lederman (2014). Although NOSK has been viewed as an important educational outcome for science students for over 100 years, it was Showalter's (1974) work that galvanized NOSK as an important construct within the overarching framework of scientific literacy. Admittedly, the phrase scientific literacy had been discussed by numerous others before Showalter (Dewey 1916; Hurd 1958; National Education Association 1918, 1920; Blough 1960, among others). However, it was his work that clearly delineated the dimensions of scientific literacy in a manner that could easily be translated into objectives for science curricula. Showalter's framework consisted of the following seven components (Showalter 1974, pp. 1–6):

- Nature of science: the scientifically literate person understands the nature of scientific knowledge.
- Concepts in science: the scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe.
- Processes of science: the scientifically literate person uses processes of science in solving problems, making decisions, and furthering his own understanding of the universe.
- Values: the scientifically literate person interacts with the various aspects of the universe in a way that is consistent with the values that underlie science.
- Science society: the scientifically literate person understands and appreciates the joint enterprise of science and technology and the interrelationships of these with each other and with other aspects of society.
- Interest: the scientifically literate person has developed a richer, more satisfying, and more exciting view of the universe as a result of his science education and continues to extend this education throughout his life.
- Skills: the scientifically literate person has developed numerous manipulative skills associated with science and technology.

NOSK and science processes (now known as inquiry or practices) were clearly emphasized in Showalter's work. The attributes of a scientifically literate individual were later reiterated by the National Science Teachers Association (NSTA 1982). The NSTA dimensions of scientific literacy were a bit expanded from Showalter's. A scientifically literate person was thus considered to be one who (NSTA 1982):

- Uses science concepts, process skills, and values making responsibly everyday decisions;
- Understands how society influences science and technology as well as how science and technology influence society;
- Understands that society controls science and technology through the allocation of resources;
- Recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;
- Knows the major concepts, hypotheses, and theories of science and is able to use them;
- Appreciates science and technology for the intellectual stimulus they provide;

- Understands that the generation of scientific knowledge depends on inquiry process and conceptual theories;
- Distinguishes between scientific evidence and personal opinion;
- Recognizes the origin of science and understands that scientific knowledge is tentative, and subject to change as evidence accumulates;
- Understands the application of technology and the decisions entailed in the use of technology;
- Has sufficient knowledge and experience to appreciate the worthiness of research and technological developments;
- Has a richer and more exciting view of the world than before as a result of science education; and
- Knows reliable sources of scientific and technological information and uses these sources in the process of decision-making.

Of particular importance to the argument made, here is the juxtaposition of NOSK and SI as it has evolved over the years, resulting in their current relationship in the NGSS. Within Showalter's delineated dimensions of scientific literacy, SI and NOSK were viewed as separate, but intimately related constructs. Students were expected to possess knowledge of NOSK and competency in the performance of scientific processes/inquiry.

3 The Emergence of the Benchmarks for Science Literacy

The *Benchmarks for Science Literacy* (AAAS 1993) continued the emphasis on the importance of scientific inquiry and NOSK. An interesting point is that the phrase "science literacy" as opposed to "scientific literacy" was used in this reform document. Most readers perceived these two phrases as synonymous, but they are not. In general, science literacy refers more to one's mastering of scientific knowledge and science processes, while scientific literacy expands on the former by stressing the use of scientific knowledge to make informed decisions with respect to personal, societal, and global issues. The differences are related, but not critically important to the argument presented here. For those who are interested, a good explication of the differences can be found in Roberts (2007) and Roberts and Bybee (2014).

Although the Benchmarks claimed to be advocating science instruction that provided an integrated view of the scientific enterprise, it was presented as a set of 12 separate chapters. With the exception of the chapter on *Common Themes* (and perhaps *Habits of Mind*), there was little attempt to provide links across the chapters. Nature of science (now referred to here as NOSK) was the first chapter in the reform document, and scientific inquiry was presented as a subtopic along with "the scientific world view" and "the scientific enterprise." There are two important observations that can be made about the Benchmarks' positioning of NOSK. The conflation of NOSK and SI, a problem that still exists (Peters-Burton 2014; Salter and Atkins 2014) is clear as SI was considered to be a subset of NOSK. Consequently, the development of scientific knowledge was not clearly differentiated from the characteristics of the knowledge. For sure, they are intimately related since the characteristics of the knowledge (NOSK) are inherently derived from the way in which the knowledge was developed. There are those who claim that it is not useful, or even inaccurate, to distinguish between NOSK and inquiry (e.g., Duschl and Grandy 2013), and they inappropriately claim that Lederman (2007) and others insist the two are distinct and not related. It is possible that the confusion between NOSK and scientific inquiry was created when the original phrase nature of scientific knowledge was shortened to nature of science in the early 1980s. Indeed, one of the more popular and early assessments of NOSK (Rubba and Andersen 1978) was titled the "Nature of Scientific Knowledge Scale." It is for this reason that the abbreviation of NOSK is used here as opposed to NOS.

A second observation is that NOSK was presented separately from the other important student outcomes. It could be argued that NOSK would have better been placed in the Common Themes outcomes. In any case, NOSK is still presented as a separate domain of knowledge. Consequently, it was at least implied that NOSK could or should be taught separately from the other science outcomes. Indeed, it is not uncommon for science teachers to begin the school year with a unit (or several days) dedicated to NOSK and it is fairly typical for science textbooks that address NOSK to have a first chapter on NOSK.

4 The National Science Education Standards "Replace" the Benchmarks

In 1996, the *National Science Education Standards* (NSES) "replaced" the Benchmarks as the primary reform document in the USA. Replaced has been used parenthetically because there are still many schools and school districts in the USA and around the world that still prefer the Benchmarks as their curricular framework for science education. Indeed, AAAS continues to provide materials related to the Benchmarks. Regardless, it is surprising that after only 3 years, the USA found it necessary to rethink their vision and develop new standards for science education. Given that the Benchmarks was a K-12 framework for reform, one would think that it would take at least 12 years of verifiable implementation/enactment for a valid assessment to be completed. Perhaps, the decision was political (i.e., The American Association for the Advancement of Science and the National Academies of Sciences), but it certainly was not an empirical decision because the Benchmarks were not implemented in classrooms long enough to collect the necessary data on their effectiveness.

The NSES (NRC 1996) situated NOSK as a separate domain of knowledge. Similar to the Benchmarks, there were standards for *Unifying Themes and Processes*, but NOSK (along with history of science) and SI were treated in separate standards, although closely related. Although the NSES did a good job of disentangling the conflation of NOSK and SI, the reader was still left with the impression that NOSK could/should be taught as a separate domain of knowledge. That is, the NSES was formatted into separate content standards chapters/sections. It can be argued that the NSES was an improvement from the Benchmarks because it recognized that NOSK and SI should be considered as subject matter alongside traditional life, earth and space, and physical science content. In retrospect, although the NSES did separate SI and NOS into two different domains of knowledge, neither the Benchmarks nor the NSES effectively communicated their visions of an integrated approach to the teaching of science. Regardless of this difference, one was hard-pressed to see NOSK being taught effectively in our science classrooms at any grade level. Nothing was/is really any different today than it was since science educators seriously began studying NOSK in the late 1950s (see Lederman and Lederman 2014).

5 Unveiling of the Next Generation Science Standards

With much anticipation and fanfare, the Next Generation Science Standards (NGSS) were made public in 2013 (NGSS Lead States 2013). They were based on the theoretical rationale presented in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012). The NGSS strongly emphasizes an integrated approach to science teaching and learning across three dimensions: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Ideas. The latter is clearly the most attentive to themes that run across all sciences, but the idea is that a concerted effort should be made in order to include all three dimensions in all instructional planning and instruction. Most important to the present discussion is that the NGSS positions NOSK as a subset of the dimensions of Science Practices and Crosscutting Concepts. Specifically, NOSK is considered to be constituted by eight understandings. Those understandings related to Science Practices are:

- Scientific investigations use a variety of methods
- Scientific knowledge is based on empirical evidence
- Scientific knowledge is open to revision in light of new evidence
- Science models, laws, mechanisms, and theories explain natural phenomena

whereas those understandings associated with Crosscutting Concepts are:

- Science is a way of knowing
- Scientific knowledge assumes an order and consistency in natural systems
- Science is a human endeavor
- Science addresses questions about the natural and material world

There was a need for further clarification of the NGSS vision with respect to a variety of issues, one of which was the lack of emphasis on NOSK. Hence, Appendix H was written in an attempt to appease the professional communities' (e.g., National Science Teachers Association) concerns about NOSK. It is odd to see eight aspects of NOSK delineated in the NGSS, given the following statement in Appendix H, "Indeed, the only consistent characteristic of scientific knowledge across the disciplines is that scientific knowledge itself is open to revision in light of new evidence" (Appendix H, p.96). The only reasonable speculation about this inconsistency is that this is a common symptom of documents that are written by a committee. The distribution of ideas commonly associated with NOSK is divided across the two dimensions in a manner that, once again, conflates SI and NOSK. So, in one way, there has been a step back to the conflation noted in the Benchmarks. However, the way NOSK has been situated, in the NGSS, is a bit more complex. That is, NOSK is positioned as a subset of Science Practices (i.e., the doing of science); however, understandings about inquiry/practices (NOSI) are positioned as a subset of NOSK. The NSES was prominent in its recognition that there was a difference between outcomes concerning students "doing" of science (e.g., observing, inferring, concluding, etc.) and knowledge "about" inquiry (NOSI). The NGSS has placed the doing of science as part of the Practices and the knowledge about inquiry as a subset of NOSK.

On the positive side, the treatment of NOSK as a separate domain of knowledge in both the Benchmarks and NSES is not evident in the NGSS. Half of the eight references to NOSK are included within the dimension of Crosscutting Concepts, and the other half are within the dimension of Science and Engineering Practices. Consistent with the integrated vision of the NGSS, NOSK has been integrated within the subject matter outcomes as opposed to being a separate domain of knowledge. This definitely implies a curricular direction that was not achieved by either the Benchmarks or NSES. Presumably, there will be no attempt to have teachers develop separate units or lessons for NOSK. However, a serious concern has been created. NOSK, in each of the dimensions to which it is assigned, is merely mentioned as a "connection" that teachers can make as opposed to an explicit standard. Students' understandings of NOSK have no stated performance expectations and so there is no reason to believe that understandings of NOS will be explicitly taught or assessed. It is well established that teachers typically do not teach what is not assessed (Dwyer 1998). Overall, in the NGSS, NOSK is relegated to the position of a connection, which teachers may choose to make or not. There is no real encouragement for teachers to embed NOSK in NGSS aligned lessons.

The conflation of NOSK and SI (in this case, Practices) remains problematic in terms of what students are expected to know or do as a result of their K-12 science education. The NGSS standards for Science and Engineering Practices are:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in arguments from evidence
- Obtaining, evaluating, and communicating information

The NGSS standards for Crosscutting Concepts are:

- Patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter
- Structure and function
- Stability and change

With respect to Practices, it is obvious that the outcomes are things that students are able to do. No doubt these are important, but understandings of NOSK are cognitive understandings, not performance outcomes. Although it has long been intuitively assumed that there is a relationship between "doing science (SI)" and "understandings about science (NOSK)," the empirical research for the last three decades has clearly indicated that this is a false assumption (Lederman 2007; Lederman and Lederman 2014). With respect to the Crosscutting Concepts, the outcomes listed are cognitive understandings, but it is unclear how the ideas listed are specific to NOSK or SI. Certainly, they are related, but not specifically related.

In the end, the instructional or curricula question/problem is that if students demonstrate the abilities specified in the Practices and understandings specified in the Crosscutting Concepts, will they have understood NOSK? Overall, students are expected to demonstrate the ability to "do" SI/ practices and some understanding of overarching themes in science, but the specified outcomes are not focused on students' understandings of the characteristics of scientific knowledge as directly derived from how the knowledge is developed. Without any explicit standards or performance expectations for NOSK (i.e., only connections are specified), it appears that the writers of the NGSS and its framework (NRC 2011) have assumed that students will come to understand NOS simply by engaging in science practices and learning about crosscutting concepts. However, the overwhelming body of empirical research, as reported in the following comprehensive reviews of the empirical literature, indicates that students will not develop informed views of NOSK if it is not explicitly integrated into instruction (Abd-El-Khalick and Lederman 2000; Lederman 2007; Lederman and Lederman 2014). "Explicit" should not be mistakenly considered as synonymous with direct instruction, as some have previously assumed (Duschl and Grandy 2013). It simply means that NOSK is brought to the forefront at various times during instruction through discussions and reflections among the students. Bringing NOSK to the forefront during instruction goes well beyond the teacher simply pointing out aspects of NOSK when appropriate, but rather involves students reflecting on their experiences as they struggle with developing science understandings as they engage with phenomena. A concrete instructional example, which has been used with students, should serve to reinforce the stated concern.

6 The Mystery Bone Activity

This activity/experience actually takes 3–4 days (depending on students' grade level) and is ideal for a biology or life science course while evolution, natural selection, and form and function are discussed. The activity has actually been used by teachers in high school and middle school classes across the USA as well as several European and Asian countries. The overall focus is on evolution, along with form and function, as opposed to the less useful memorization of bones and their locations. The activity can be used in high school or middle school and contributes to specific NGSS standards in Table 1:

As students learn about evolution and the skeletal system, they could learn about various aspects of NOSK as well. In particular, the ideas that scientific knowledge is tentative, a function of human creativity and subjectivity, derived from observations and inferences, and

Table 1 Relevant middle and high school NGSS Standards

Middle school	High school
Middle school-learning strand 4: natural selection and adaptations Performance expectation LS4–1: analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. Performance expectation LS4–2: apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. Science and engineering practices: analyzing and interpreting data and constructing explanations Disciplinary core ideas: evidence of common ancestry and diversity, natural selection, and adaptation Crosscutting concepts: patterns, cause and effect	High school-learning strand 4: biological evolution: unity and diversity Performance expectation LS4–1: communicating scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence Performance expectation LS4–2: construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species die to mutation and sexual reproduction, (3) competition for limited resources, (4) the proliferation of those organisms that are better able to survive and reproduce in the environment Science and Engineering Practices: analyzing and interpreting data, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and Communicating evidence Disciplinary core ideas: evidence of common ancestry and diversity, natural selection, and adaptation Crosscutting concepts: patterns, cause and effect

an understanding that scientific investigations can take a variety of forms as opposed to a single scientific method can all be conceptually understood by students through their experience with this activity. However, as presented here, engagement of students in reflections on their thinking and behaviors and student-centered discussions about NOSK discussions have been removed. The purpose is to illustrate how an NGSS-aligned experience can miss the opportunity to also teach about NOSK and SI because NOSK has been marginalized/situated as possible connections that teachers could make.

Grade level: middle, and high school

Prerequisite knowledge: minimal knowledge of skeletal systems

Instructional scenario:

1. On the first day that students begin their study of evolution and skeletal systems, they are given an owl pellet (see Fig. 1). Students are asked to work in pairs as they dissect the bones from the owl pellet. Owl pellets are indigestible food (i.e., bones and hair) regurgitated by barn owls several times a day. Since bones are not digestible by the owls, they are embedded within the pellets (Fig. 2).
2. After all the bones are removed from the pellets, the students are asked to sort the bones into groups of similar ones. After a discussion on the different types of bone forms, the students are asked to use their knowledge of skeletal systems to put the bones into a formation that might resemble the skeletal system of a real animal. Student groups are then asked to defend their positioning of the bones, that is, why they put the bones together as they did. Following this discussion,

Fig. 1 Owl pellet

Fig. 2 Dissected owl pellet

the students are provided with a diagram of a vole (Fig. 3) and asked to match the bones on the vole diagram to the bones they collected from the owl pellets.

3. The next day, there is a class discussion about the structure/form of the various bones and their locations in the vole skeleton. Students are asked where the largest and thickest bones are found and where the smallest and thinnest bones are found. The goal of the discussion is to have students realize that the structure/form of the various bones is related to their function and location (e.g., supporting weight, protection, etc.).
4. Following this discussion, the students in groups of 4–5 are given a disarticulated skeleton of an unidentified animal and their task is to put it together. Students are expected to use the knowledge of skeletons that they learned from the owl pellet activity to infer the structure of this new and unidentified animal (see Fig. 4). The disarticulated skeletons are from rabbits, cats, and minks, and are readily available from any biological supply company. It is likely that the students will not complete this task before the end of the class period, so it typically runs over to the next day.
5. The following day, the students complete the assemblage of their skeleton and another discussion ensues about the structure and functions of the bones in the skeleton. Students are not expected to identify from which animal the bones

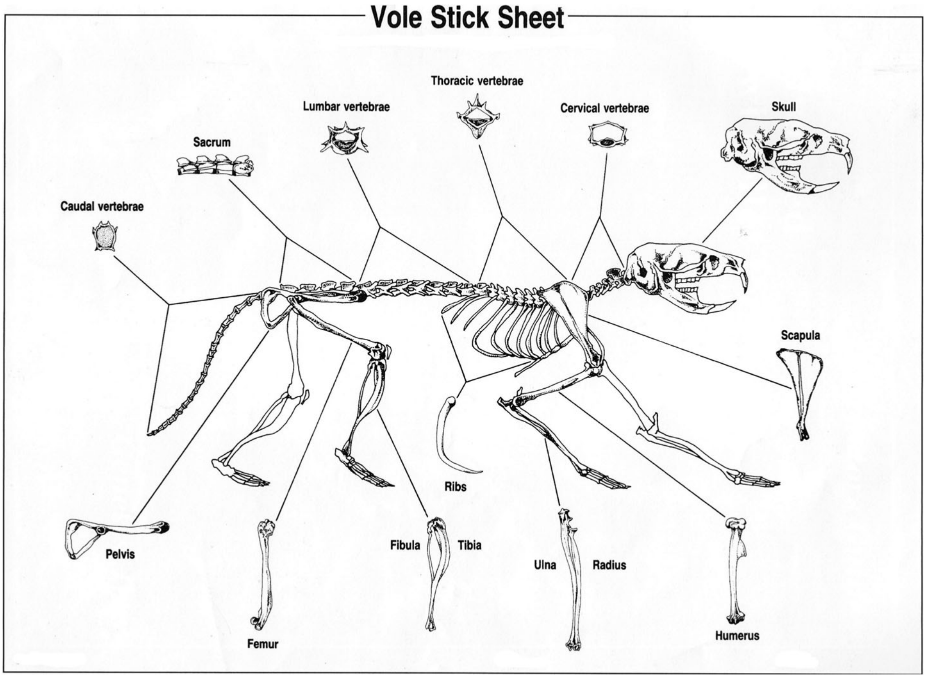

Fig. 3 Vole stick sheet

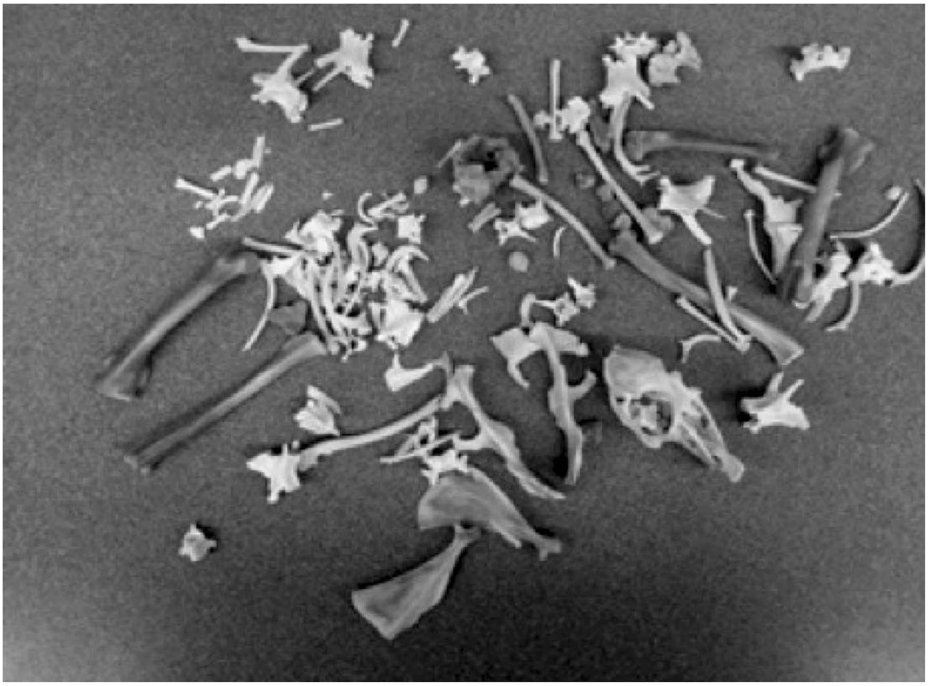

Fig. 4 Disarticulated skeleton (cat, rabbit, or mink)

come, but rather mainly solidify the relationship between the structure and functions of bones in the skeletal system.

6. The next day, groups of students are given envelopes that have a set of bones, from an extinct animal, that are represented on laminated paper (see Fig. 5). They are asked to use their knowledge of skeletal systems to construct the animal's skeletal system, just as paleobiologists do.
7. Students are encouraged to circulate and view the constructions of other groups out of curiosity or to help them with their own constructions. As constructions near completion, the teacher can take pictures of the various constructions with an iPad for later projection on a SMART Board.
8. The constructions of each group are projected for class discussion. Each group explains the reasons for the placement of the bones in the constructed skeleton. As this is done, where appropriate, the teacher questions students to elaborate further about their logic when placing the bones together.
9. The teacher reveals scientists' construction of the skeleton and also the inferred appearance of the animal with its skin on (see Figs. 6 and 7). Students are typically surprised to see the placement of the bones extending from the forearm digit of the animal because they have previously only seen the skeletons of terrestrial animals.
10. The teacher explains that the organism is believed to be one of the first "dinosaur-like" animals that could fly (actually glide). Its resemblance to a reptile is emphasized because dinosaurs, at that time, were believed to be related to reptiles at that time.
11. The students are then informed that during the past decades, scientists have decided that the bones supporting the wing in Fig. 6 should be moved to the second forearm digit to better support the wing.
12. Figure 8 is revealed along with Fig. 9.
13. The teacher asks students about the appearance of Fig. 9 as opposed to Fig. 7 The students quickly notice that Fig. 9 is more birdlike as opposed to looking like a reptile. The teacher explains that we currently have a better understanding about the relationships among dinosaurs, reptiles, and birds. If it is a high school class that has studied, or are studying, evolution, the teacher could ask students why the inferred appearance has changed.

In summary, this activity fits quite nicely within a biology class during the study of vertebrates, skeletal systems and the form and function of bones, and evolution.

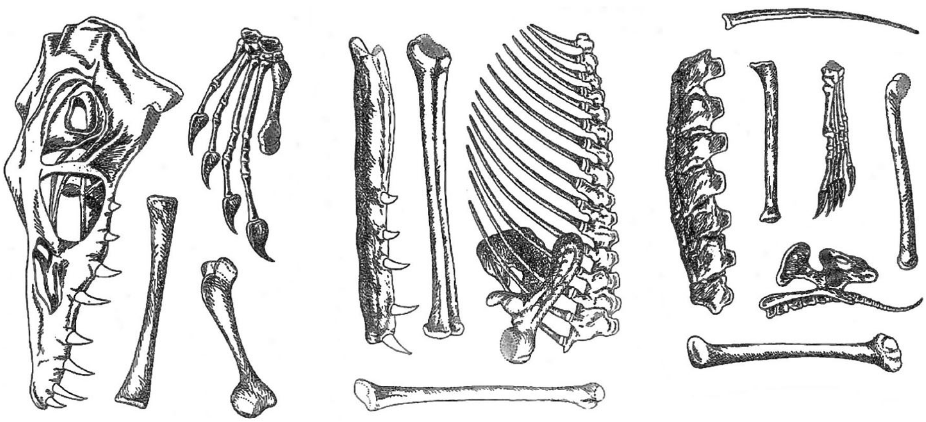

Fig. 5 Mystery bones

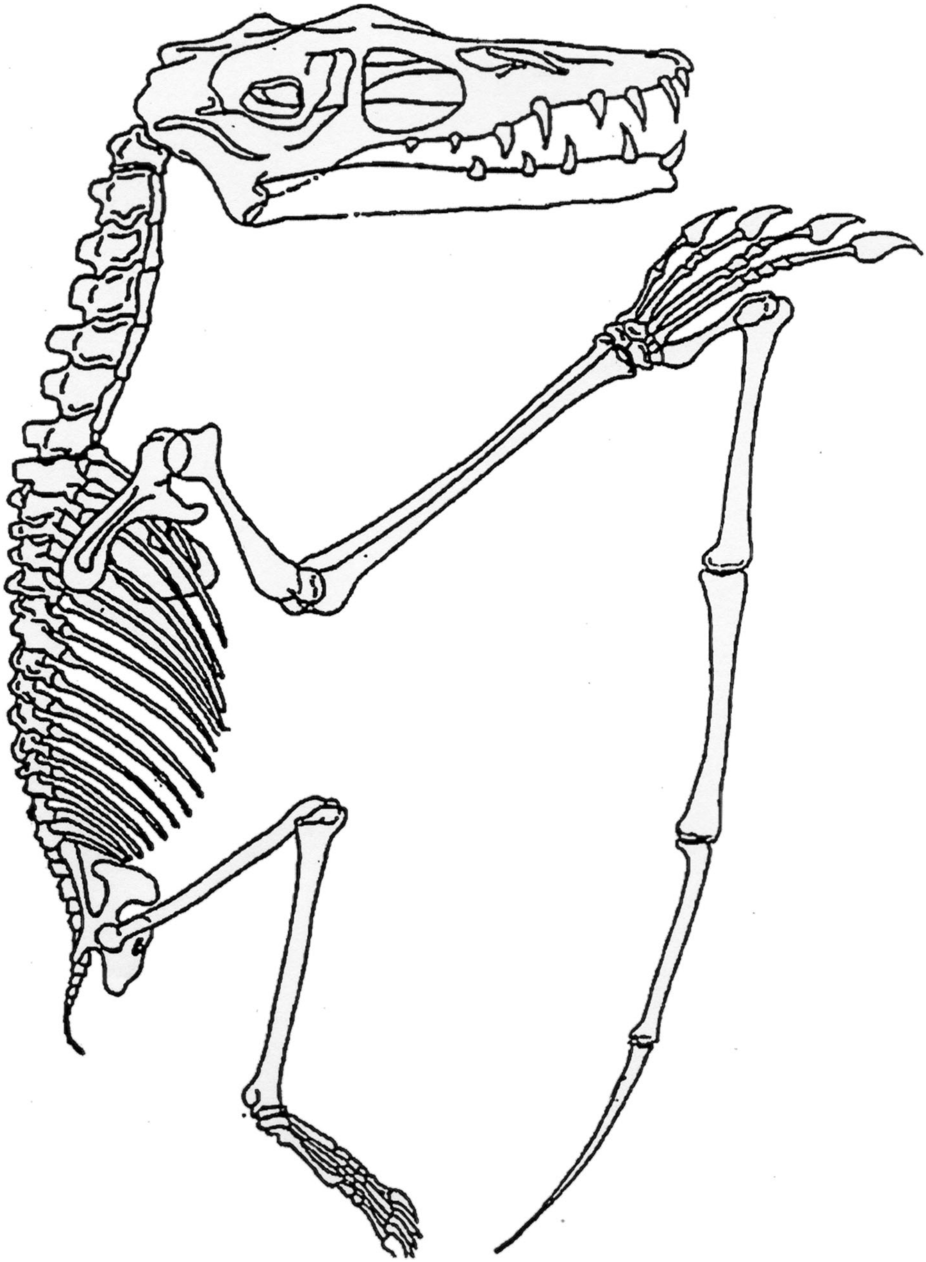

Fig. 6 Reconstructed skeleton of *Scaphoenathus crassirostris*

The described activity clearly engages students in Science Practices, Disciplinary Core Ideas, and Crosscutting Concepts, as specified at the beginning of the experience, in an authentic and meaningful manner. The activity as described is well aligned with the vision of the NGSS or any curriculum that promotes students' engagement with authentic and meaningful science activities. The main question to ask is how

Fig. 7 One paleontologist's inference of *Scaphoenathus crassirostris* with its skin on

well will students develop or reinforce the understandings of NOSK specified in the NGSS, or any other aspects of NOSK described in the literature. There are obvious, and not so obvious, places where students could be engaged in discussions that relate to NOSK. But, will these connections be made by the teachers and students? Since there are no standards or performance expectations specified for NOSK (or instructional objectives in a curriculum that is not based on the NGSS), making NOSK explicit is left up to the whims of the teacher (NGSS Lead States 2013). This is the concrete impact of how NOSK has been contextualized in the NGSS. Again, without explicit attention to NOSK, the research clearly indicates that students are not likely to come to understand NOSK, let alone be able to make use of it in real life situations. They are likely to learn about the various forms of bones, the various functions they perform, and how skeletal systems are "put together" to the benefit of the vertebrate in question. Unfortunately, as presented, this activity is a lost opportunity for students to develop their understanding of NOSK. It is typical of a lesson/activity that simply focuses on doing SI and assumes that students will implicitly develop understandings of NOSK. What needs to be done by teachers is have students

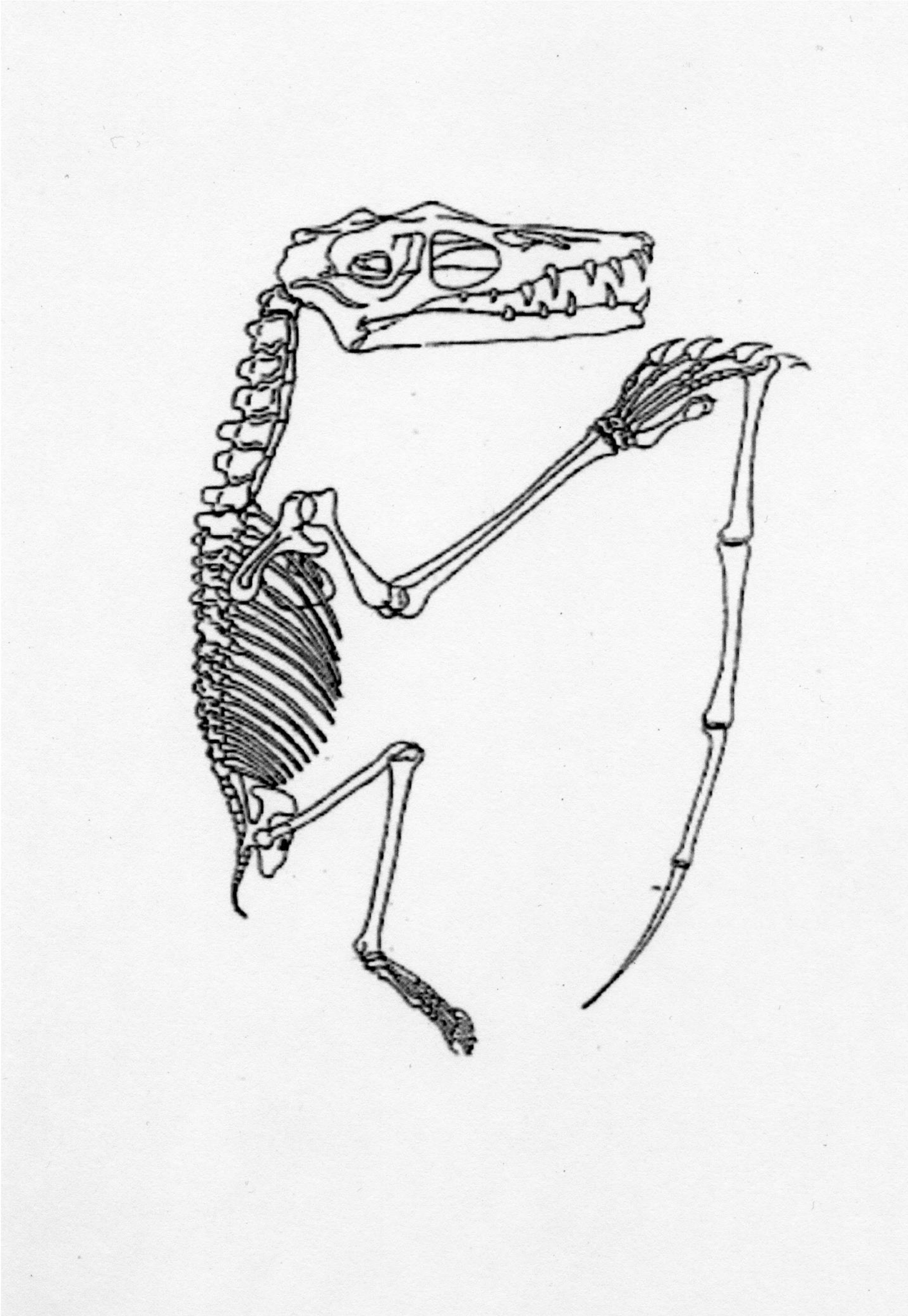

Fig. 8 Reconstructed skeleton of a *Pterosaur sp.*

reflect on the activity experienced and ask questions that lead to the discussion of the appropriate aspects of NOSK.

Fig. 9 Another paleontologist's inference of *Pterosaur sp.*

The NGSS is an improvement from the Benchmarks and NSES. NOSK and SI are integrated into the other science outcomes, and it appears that teachers following the vision of the NGSS will be less likely to teach NOS as a separate topic or unit. However, the NGSS is a step backward from the previous reform efforts because there are no clearly stated outcomes or assessments related to NOSK. The NGSS had the advantage of the much more extensive empirical research base on students' learning about NOSK than was available to the developers of the Benchmarks and NSES, but the NGSS framework is not aligned with the research on NOSK.

7 Quo Vadis?

Is this all "much ado about nothing?" Does the analysis provided here have any significant implications for science education? Does it really make a difference whether students learn about NOSK? These are important questions, and it brings us full circle to the work of NSTA (1982), Showalter (1974), among others. In the end, we want students to not only learn to perform Science and Engineering Practices, understand Disciplinary Core Ideas and Crosscutting Concepts, but we also want them to be able to apply what they have learned to make informed decisions about personal, societal, and global issues. There are certainly strong arguments that can be made for the value of knowing science in and of itself (Driver et al. 1996). These are ultimately arguments of the inherent value of education (Green 1971).

Being educated is of value in and of itself, and it is not necessarily a means to a pragmatic end. Alternatively, scholars such as Bertrand Russell (1940, 1950) went further and felt that relegating teachers to simply facilitating the development of students' understandings of the knowledge, values, and mores of a society was antithetical to what should be the role of the teacher. He felt that such an approach led to fanaticism and isolation from the global community. He felt that developing students' free and critical thinking enhanced and improved our society. Although written almost 80 years ago, Russell's ideas of education could not be more aligned with the goals of developing a scientifically literate public.

It goes without saying that the overwhelming majority of the students in our science classes will not become professional scientists. Equally true is the recognition that our lives are impacted by an ever-increasing advancement of scientific and technological knowledge, along with the personal and societal issues this knowledge brings. Our citizenry needs, and will need, to be informed consumers of science and make informed decisions on these issues. After graduation from high school or college, unless an individual pursues a career in a STEM field, they will probably never perform a formal scientific investigation again. Their decisions will need to be made based on their ability to make sense of the claims made by the scientific community. They will need to know how the scientific knowledge behind the issues was developed and how to weigh the status of the existing evidence. This ability is intimately connected to individuals' understanding of SI (not the *doing* of scientific inquiry) and NOSK (Sadler et al. 2004; Walker and Zeidler 2003; Zeidler et al. 2002). In the NGSS, understandings of SI are included within the construct of NOSK, and are presently just connections that a teacher can help students make. They are not standards, and there are no outcomes to be assessed.

In summary, how SI and NOSK are contextualized and related has significant implications for curriculum outcomes and instructional practice. If NOSK is embedded implicitly within an SI focus, instruction will focus on students doing SI and NOSK will be learned by chance, if learned at all. Although the NGSS has progressed from the conflation and isolated attention to SI and NOSK, they represent a step backward in terms of what empirical research tells us about how students come to learn about NOSK and become scientifically literate. The shifting contextualization of SI and NOSK in the reform efforts in the USA was used as an example, but the concern applies to reforms and curricula worldwide.

Compliance with Ethical Standards

Conflict of Interest The author declares no conflict of interest.

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