Supplementary Material

|  |  |  |
| --- | --- | --- |
| number | Author | Definition |
| 1 | (Abd-El-Khalick & Akerson, 2004) p. 792 | Explicit, reflective approach to NOS instruction. The approach should not be confused with didactic teaching, and does not entail drilling students to reiterate certain ideas about NOS. The term“explicit”is not meant to refer to“explicit teaching,”which relates to prescribed generic teaching strategies that are“most applicable in those areas where the objective is to master a body of knowledge or learn a skill”(Rosenshine & Stevens, 1986, p. 377). Instead, the term is intended to highlight our notion that NOS understandings are cognitive instructional outcomes, which should be intentionally targeted and planned for in the same manner abstract scientific concepts and theories are. The fact that ideas associated with atomic or evolutionary theory are translated into specific teaching objectives does not automatically entail that they will be taught didactically. Constructivist approaches could be used to teach about NOS in the same way they are used to help students build their own conceptions of abstract scientific ideas.By comparison, the term“reflective”in the label“explicit-reflective”is meant to emphasize certain instructional elements: They include providing students with opportunities to analyze their activities from within a NOS framework, map connections between these activities and those of scientists, and make conclusions about scientific epistemology. Simply put,an explicit-reflective approach emphasizes student awareness of certain NOS aspects in relation to their learning activities, and student reflection on these activities from within a framework comprising these NOS aspects. |
| 2 | (Akerson et al., 2000) p. 301 | This reflective component of the intervention aimed to help participants articulate and elaborate their acquired NOS understandings and apply those understandings in various contexts. |
| 3 | (Akerson & Abd-El-Khalick, 2005) p. 8 | By explicit instruction, we mean that the teacher points out to the students when NOS aspects are being emphasized in an inquiry science lesson such as asking students to reflect on whether their results mean their work is “done”, and emphasizing to them that, yes, they do have evidence indicating a specific explanation may be accurate, but that there may be competing explanations, or they may reinterpret the evidence or collect more evidence that would cause them to change their claims. By helping students to realize that their own scientific claims are tentative, and then explicitly asking them to relate what they did to what scientists do, there is a better chance that they will develop improved NOS conceptions. |
| 4 | (Akerson et al., 2007) p. 753 | Explicit instruction refers to drawing the learner’s attention to key aspects of the NOS through discussions and written work following engagement in hands-on activities. Reflective NOS instruction requires learners to think about how their work illustrates the NOS and how their inquiries are similar to or different from the work of scientists. |
| 5 | (Akerson et al., 2010) p. 725 | Explicit reflective instruction refers to drawing the learner’s attention to aspects of NOS explicitly through questioning strategies, discussions, written work, and asking them to reflect on the science they are learning by thinking of those aspects and how their activities in science are similar to what scientists do. An additional component to explicit reflective instruction is specific assessment of NOS aspects that are targeted in instruction. This assessment is formative and indicates to the teacher which aspects students still do not understand so she can provide more explicit instruction. |
| 6 | (Alan & Erdogan, 2018) p. 696-697 | An explicit–reflective approach suggests the importance of teaching aspects of NOS with an intentional focus, rather than as a by-product of engagement in instruction. The term ‘explicit’ does not refer to didactic teaching strategies here. Instead, it emphasizes that NOS understandings are cognitive learning outcomes and should therefore be intentionally targeted during instruction. (Khishfe & Abd‐El‐Khalick, 2002) |
| 7 | (Angle, 2020) p. 686 | An explicit and reflective method of instruction pertaining to NOS is defined as an “… approach [that] emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects” (Khishfe & Abd‐El‐Khalick, 2002, p. p.555) |
| 8 | (Aydin et al., 2013) p. 990 | for explicit instruction—in which NOS is specifically planned for, taught, and assessed |
| 9 | (Brunner & Abd-El-Khalick, 2020) p. 438 | Research has shown that NOS instruction must be explicit and reflective—that is, it must be specifically planned for, as well as reinforced with structured opportunities for student reflection (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd‐El‐Khalick, 2002). |
| 10 | (Bugingo et al., 2022) p. 29 | Explicit approach addresses instructional practices that will help students to discover NOS aspects in class, while refective approach gives students the opportunity to draw their own interpretations and conclusions and not being passive only (Akerson et al., 2000). So, if teachers know that students are not empty vessels (i.e., students previously hold beliefs on concepts) about nature of science (Clough, 2006), they will be able to help students to incorporate new knowledge into learned concepts or theories (Matthews, 1997). According to Clough (2006, p. 474), “explicit and refective highly contextualized NOS instruction plays a crucial role in NOS instruction by overtly drawing students’ attention to important NOS issues entangled in science content and its development.” The explicit approach also refers to bringing learners’ attention to NOS aspects through discussion, guided refection activities, probing questions and assessments, investigations, and diferent examples of history about science. In explicit approach, the views of NOS are improved through planned objectives, assessments, and necessary feedback to the students instead of being originated as a consequence or a side efect of inquiry activities (Schwartz et al., 2004 and Abd–El–Khalick, 2013). In explicit approach, all NOS aspects are targeted. |
| 11 | (Buaraphan, 2012) p. 357 | An explicit-reflective manner, i.e., teachers make aspects of NOS an explicit part of classroom discourse and provide learners opportunities to reflect upon and explain their ideas about NOS. the label ‘explicit’ is curricular in nature while the label ‘reflective’ has instructional implications. The label ‘‘explicit’’ is intended to emphasize the need for the inclusion of specific NOS learning outcomes in any instructional sequence aimed at developing learners’ understanding of NOS. In this case, the comprehension of NOS is a cognitive instructional outcome that should be intentionally targeted and planned for in the same manner as other scientific concepts. Notably, the ‘‘explicit’’ component of the explicit-reflective approach to NOS instruction does not entail a certain pedagogical approach (Abd-El-Khalick and Akerson 2004, 2009). On the one hand, the ‘‘reflective’’ component does entail instructional elements that need to be incorporated into pedagogical approaches undertaken within the explicit-reflective approach. This element refers to the inclusion of structured opportunities designed to encourage learners to examine their science-learning experiences from within an epistemological framework, which would focus on questions related to the development and validation of, as well as the characteristics of, scientific knowledge. That is, students should have opportunities to analyze their activities from within an NOS framework, map connections between these activities and those of scientists, and make conclusions about scientific epistemology. Simply, an explicit-reflective approach emphasizes student awareness of certain NOS aspects in relation to student learning activities and student reflection on these activities from within a framework comprising these NOS aspects (Abd-El-Khalick and Akerson 2004, 2009). In addition, Hanuscin et al. (2010) elaborated on four overarching criteria of the explicit approach to teaching NOS: teachers plan to teach a particular aspect of NOS; students are made aware of the target aspect of NOS; students are provided an opportunity to discuss and/or reflect on their ideas about the target aspect of NOS; and teachers elicit students’ ideas about NOS before, during, or at the conclusion of the activity. |
| 12 | (Çelik, 2020) p. 317 | In the explicit approach, the scientific activities, the history of science or the philosophy of science and NOS activities are being related to the content of the courses (Peters, 2012). In the teaching of NOS, the critical point of explicit and reflective teaching is to ask questions that encourage students to discuss the aspects of NOS (Khishfe & Abd-El-Khalick, 2002; Lederman & Lederman, 2019). |
| 13 | (Çil, 2014) p. 340 | Within this framework, the term explicit is not identical to didactic or direct instruction. It emphasizes that learning about NOS should be planned intentionally for learning science concepts or content and complex science theories. It is possible that teachers can prefer different pedagogical approaches including those that are active, student-centered, collaborative, and/or inquiry-oriented in nature (Abd-El-Khalick & Akerson, 2009). The “reflective” component of the explicit reflective approach to NOS was designed to encourage the learners to look at their own science learning experiences from the perspective of an epistemological framework (Abd- El-Khalick & Akerson, 2009). Abd-El Khalick and Akerson (2004) categorized this component of the approach into structured and unstructured, and written and oral exercises. |
| 14 | (Çil & Çepni, 2016) p. 46 | Within this framework, the term explicit has curricular implications, while the term reflective has instructional implications. Explicit instruction is not identical to didactic or direct instruction. Rather, it emphasizes that teachers deliberately and intentionally teach NOS, such as complex scientific theories, concepts, knowledge and skills in their classrooms. The reflective component of the explicit reflective approach is designed to encourage learners to examine their own science learning experiences in an epistemological framework |
| 15 | (Chanetsa & Ramnarain, 2023) p. 2 & 10 | Explicit approaches to teaching NOS clearly state NOS understanding as an objective, and contexts are provided which allow interaction with the NOS aspects. An explicit reflective approach is one in which the outcome of the training is aimed at understanding NOS aspects which are defined explicitly rather than assuming that NOS understanding is achieved through activities such as scientific inquiry which have other outcomes (Pleasants, 2017). |
| 16 | (Chen et al., 2022) p. 4 & 7 | The explicit-reflective approach assumes that students learn about NOS by participating in activities through which they design, collect data, analyze and interpret, and communicate findings with peers. After the activity, teachers explicitly discuss NOS aspects included in the activity through the participation of students. In this study, the explicit-reflective approach means that the textbook authors explicitly mentioned the NOS aspect as well as provided explanations and examples for addressing that aspect. |
| 17 | (Clough, 2006) p. 466 | … learning and teaching the NOS should be seen as a cognitive objective (Lederman, 1998) that is explicitly planned for in a way that draws students’ attention to important NOS issues when teaching science. |
| 18 | (Clough, 2011) p. 2 | Explicitly planning for and drawing students’ attention to NOS does not mean lecturing to them about it. Rather, when exclusively focusing on NOS or addressing it in the context of laboratory activities, videos, reading assignments, and interactive science content presentations, try asking questions. The kinds of questions that explicitly raise NOS ideas and can be used in most any lesson to get students thinking about how science and scientists work. |
| 19 | (Dai et al., 2021) p. 660 | NOS is best learned through explicit and reflective instruction, specifically when teachers explicitly design lessons to include NOS issues and provide students with opportunities to reflect on their class experiences (e.g., Lederman 2007). |
| 20 | (Deniz, 2011) p. 747 | Proponents of explicit-reflective instruction suggest that NOS ideas should be made an explicit part of instruction by engaging students in specifically designed NOS activities, discussions and reflection. |
| 21 | (Dogan et al., 2013) p. 425 | However, explicit reflective approach intentionally draws learners’ attention to aspects of NOS through discussions, guided reflection and specific questioning in the context of activities, investigations, and historical examples. By doing reflection as a part of explicit approach students are encouraged to think about how their work illustrates NOS, and how their inquiries are similar to or different from the work of scientists. Therefore, any attempts to foster better understanding of NOS should provide students conceptual tool that are explicit and reflective (Abd-El-Khalick & Lederman, 2000). |
| 22 | (Dunlop & de Schrijver, 2020) p. 224 | As explicit and reflexive teaching of the nature of science is central to enable students to develop understandings of NOS (Lederman 2006), it follows that teaching NOS does not entail only lecturing, but rather implies designing lessons to address NOS issues where students construct a proper understanding of and make connections between what they experience and the NOS issues at hand (Khishfe and Abd-El-Khalick 2002) |
| 23 | (Duschl & Grandy, 2013) (version 1) p. 2111 | Version 1 advocates that teachers explicitly link the consensus statements to features of science lessons and activities. |
| 24 | (Duschl & Grandy, 2013) (version 2) p. 2111 | Version 2 advocates students engage in domain-specific scientific practices during weeks or months long curriculum units that focus the learners’ attention on the model building and refining enactments found in measuring, observing, arguing from evidence and explaining that are part of the growth of scientific knowledge. |
| 25 | (Edgerly et al., 2022) p. 3 | Abd-El-Khalick (2013) noted that we must get students to think about the NOS, not just engage in science tasks that accurately reflect NOS. Indeed, studies have repeatedly demonstrated that teachers must employ the explicit-reflective framework when teaching NOS (e.g., Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Edgerly et al., 2021; Khishfe & Abd-El-Khalick, 2002; Kruse et al., 2017; Lederman et al., 2014). However, as is made clear by Lederman and Lederman (2019), an explicit-reflective approach does not mean simply presenting a list of ideas to be memorized. |
| 26 | (Edmondson et al., 2020) p. 659 | NOS teaching and learning that is both explicit and reflective (Lederman 2007). In other words, NOS instruction ought to be intentionally designed to have a positive impact on learners in order to maximize that effect. |
| 27 | (Erumit & Yuksel, 2022) p. 6 | The explicit-reflective approach in NOS teaching is based upon explicitly emphasizing NOS and its critical aspects through discussions and gives students opportunities to reflect on their understanding (Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). |
| 28 | (Erumit & Akerson, 2022) p. 717 | The explicit and reflective method for teaching NOS was utilized in this study. This method is based on teaching NOS in a purposive manner, drawing students’ attention to certain NOS aspects and being explicit in emphasizing these key concepts through discussions, and providing students opportunities to reflect on their understandings of the NOS by making connections between different topics and activities (Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). |
| 29 | (Garcia-Carmona, 2022) p. 688 | This means that NOS should be regarded as (i) specific curricular content with its own learning objectives and that its implementation in class needs (ii) a design of activities that foster pupils’ reflection about and discussion of NOS issues and (iii) a specific plan for evaluating the pupils’ achievements and learning difficulties (García-Carmona, 2021b; Schwartz et al., 2004). |
| 30 | (Howe, 2009) p. 397 | having students explicitly and reflectively consider NOS tenets during instruction (Howe & Rudge, 2005; Khisfhe & Abd-El- Khalick, 2002). Explicit learning means that through some aspect of instruction, one or more of the relevant NOS tenets are directly targeted for students to evaluate. Reflective learning underscores that students must be challenged to develop their own conceptual understanding of the NOS tenets, in contrast to the alternative (didactic) approach in which a teacher “tells” students how the NOS tenet applies to a given situation. |
| 31 | (Khishfe et al., 2002) p. 554 | The explicit and reflective approach ‘‘should be planned for instead of being anticipated as a side effect or secondary product’’ ‘‘explicit’’ does not refer to didactic or explicit teaching strategies, but is meant to highlight the notion that NOS understandings are cognitive instructional outcomes that should be intentionally targeted and planned for , the term ‘‘reflective’’ in the label ‘‘explicit and reflective’’ is associated with instructional elements. The term refers to providing students with opportunities to analyze the activities in which they are engaged from various perspectives (e.g., a NOS framework), to map connections between their activities and ones undertaken by others (e.g., scientists), and to draw generalizations about a domain of knowledge Simply put, an explicit and reflective approach emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects. What is it not?: First, it cannot be overemphasized that this approach should not be confused with didactic teaching. An explicit and reflective approach does not entail drilling students to reiterate certain generalizations about the nature of scientific knowledge. Second, the term explicit in the label ‘‘explicit and reflective’’ should not lead the reader to construe the approach in the narrow and technical sense of explicit teaching, which relates to prescribed generic instructional strategies that are ‘‘most applicable in those areas where the objective is to master a body of knowledge or learn a skill which can be taught in a step-by-step manner‘‘ (Rosenshine & Stevens, 1986, p. 377). |
| 32 | (Krajewski & Schwartz, 2014) p. 4 | Explicit-reflective NOS instruction intentionally draws learners’ attention to NOS aspects through discussion, instruction and examples. It emphasizes the concept that learning about NOS should be intentionally planned. The reflective in ‘explicit reflective’ refers to structured opportunities designed to encourage learners to examine their science learning experience from within an epistemological framework. The reflective component often takes the form of questions or prompts embedded within science learning activities |
| 33 | (Küçük, 2008) p. 18 | Explicit approaches, where specific aspects of the NOS were addressed purposively and explicitly, often in the context of science history, philosophy, or inquiry-based instruction. |
| 34 | (Lederman & Lederman, 2014) p. 237 | Explicit is not synonymous with direct instruction. It simply means that NOS is brought to the forefront at various times during instruction through discussions facilitated by the teacher and reflections among the students. |
| 35 | (Lewthwaite, 2007) p. 110 | As Lederman and Zeidler (1987) suggested, facilitating the teacher candidates’ understanding of the nature of science is best done by infusing strategies into science methods courses that elicit, confront, and challenge one’s understandings of the NOS. This was also suggested by Solomon, Duveen, Scot, and McCarthy (1992), who stated that explicit reflection instruction about the NOS, integrated within a conceptual-change approach, might serve better to enhance preservice elementary teachers’ NOS views. |
| 36 | (Lin et al., 2012) p. 1008 | The explicit-reflective approach means that the targeted NOS conceps‘are made “visible” within instruction through reflective discussion with students about the practice of science’ (Lederman, 2006b, p. 312). |
| 37 | (Matkins & Bell, 2007) p. 138 | The explicit-reflective instruction approach (Khishfe & Abd-El Khalick, 2002) provides students with a framework to analyze science activities for nature of science aspects and to reflect upon the similarities and differences between the classroom science experience and the experiences of practicing scientists. |
| 38 | (McComas et al., 2020) p. 69-70 | What is often referred to as explicit (i.e., purposeful and overt) NOS instruction seems to have appeared first in Akindehin (1988), who stated that enhancing learners’ conceptions of NOS “should be planned for instead of being anticipated as a side effect or secondary product” of engagement with science (p. 73). That is, effective NOS instruction is purposely planned for, and it overtly raises NOS ideas and issues during science instruction. Abd-El-Khalick and Akerson (2004, p. 792) write that the term “explicit” means that “NOS understandings as cognitive instructional outcomes, should be intentionally targeted and planned for in the same manner abstract scientific concepts and theories are.” In other words, effective teaching of NOS—just like effective teaching of science content, such as the phases of mitosis, the rock cycle, or Newton’s laws of motion—demands that specific instructional objectives are clearly and overtly addressed. Reflective NOS instruction, on the other hand, emphasizes that NOS should be taught in a manner that requires students to be mentally engaged and think about and understand NOS ideas and issues rather than merely repeating information. Furthermore, reflective NOS teaching includes “providing students with opportunities to analyze their activities from within a NOS framework, map connections between these activities and those of scientists, and make conclusions about scientific epistemology” (Abd-El-Khalick & Akerson, 2004, p. 792). Reflective NOS instruction is in stark contrast to simple memorization and mere recall. Williams and Rudge (2016, p. 412) emphasize that “Reflective refers to students having the opportunity to come to their own conclusions about NOS aspects and not just repeating what the instructor tells them.” The emphasis on reflective NOS instruction draws from an understanding of how people learn, acknowledging that learning is an active mental process whereby learners use their prior knowledge to make sense of incoming stimuli. Beane and Apple (1995, p. 15-16) state that “people acquire knowledge by both studying external sources and engaging in complex activities that require them to construct their own knowledge.” In the end, a learner’s understanding reflects the connections and meaning he or she makes. Explicit NOS instruction does not mean lecturing about it or imposing NOS concepts; rather, it means that teachers intentionally design a curriculum to address particular NOS concepts, including setting objectives, planning activities and questions, and preparing assessments. Reflectively teaching refers to helping students make connections between their experiencing activity and targeted NOS (Clough, 2006; Schwartz et al., 2004). |
| 39 | (McComas, 2015) p. 490 | it is most effective to integrate NOS into science lessons explicitly and contextually. Teachers should look for places in existing content lessons where NOS could be introduced. NOS lessons must be woven into existing lessons through inquiry, stories, and explicit instruction throughout the school year and by making reference to the specific biological content being explored. |
| 40 | (McDonald, 2010) p. 1137 | An explicit NOS instructional approach deliberately focuses learners’ attention on various aspects of NOS during classroom instruction, discussion, and questioning. This type of instructional approach is based on the assumption that NOS instruction should be planned for and implemented in the science classroom as a central component of learning, not as an auxiliary learning outcome. |
| 41 | (Mesci et al., 2023) p. 2 | Explicit/reflective NOS teaching is an approach which includes emphasizing learning outcomes of NOS aspects, drawing attention to NOS in relation to other learning experiences, reflecting students' experiences, and evaluating NOS aspects (Abd-El-Khalick & Akerson, 2004). |
| 42 | (Metin Peten, 2022) p. 166-167 | the Explicit-Reflective approach considers that a direct effort is required to teach NOS contrary to the implicit approach. According to this approach, while teaching the NOS, activities involving scientific research skills, scientific discussions, and models are carried out with teachers or students. Then, the students or teachers tried to comprehend the NOS by giving feedback on the activities (Gess-Newsome, 2002). |
| 43 | (Nyarko & Rudge, 2022) p. 2 | Rudge and Howe (2009), describe the explicit and reflective strategy as incorporating the nature of science ‘as a planned instructional outcome of science lessons (activities and discussions), rather than left implicitly for students to figure out on their own or added as a tangential discussion topic’ (p. 563). Rudge and Howe further explain that by reflective, they mean that students need to be encouraged to develop more sophisticated understandings of nature of science issues as a result of their own deliberations, as well as come to recognize the implications of insights gained from discussions about particular examples for their understanding of science in general. (p. 564) |
| 44 | (Ozgelen et al., 2013) p. 4 | … ‘‘an explicit and reflective approach, [which] emphasizes student awareness of certain NOS aspects in relation to the science based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects’’ (Khishfe & Abd‐El‐Khalick, 2002, p. 555) |
| 45 | (Parrish et al., 2020) p. 360 | By explicit we mean that the targeted NOS subdomains are intentionally brought to the attention of teacher-learners. This can be done in numerous ways, such as through discussion, questioning, or reading about NOS. By reflective we mean that teacher-learners actively engage in critical thought in which they carefully consider their existing beliefs about NOS with reference to new information. Reflection can occur in a multitude of ways, such as through whole-class or small-group discussion, reflective journaling, or “minds-on” activities like concept mapping. |
| 46 | (Peters-Burton, 2013) p. 236 | Teachers learned that explicit instruction of NOS meant setting goals for students and pointing out when they were acting like scientists instead of expecting the students to infer this information from a laboratory activity. |
| 47 | (Posnanski, 2010) p. 591 | … promote an explicit approach in which certain aspects of NOS are incorporated into science content courses. These explicit experiences allow ample time for discussing NOS as related to science content delivery, learning to teach NOS, and using an inquiry-based instructional approach. |
| 48 | (Quigley et al., 2010) p. 888 | Explicit reflective instruction ‘‘should be planned for instead of being anticipated as a side effect or secondary product’’(Akindehin, 1988, p. 73), meaning forethought into the types of questions to be asked and how the aspects are going to be explicitly taught are essential to effective NOS instruction. The reflection component of explicit reflective instruction includes providing students with opportunities to reflect on the class activities regarding the different NOS aspects. |
| 49 | (Russell & Aydeniz, 2013) p. 531 | Explicit/reflective NOS instruction, according to Abd-El-Khalick and Lederman (2000), involves discussions which emphasize the specific tenets of NOS and often historical examples of how scientific knowledge was garnered making the epistemology of the scientific enterprise clear to students. This explicit, though not necessarily didactic, instruction is then combined with ample opportunities for the learners to think about, process, and discuss their developing understandings of NOS. |
| 50 | (Scharmann et al., 2005) p. 28 | explicit, meaning that it should be an independent topic taught within a science course and not left to emerge implicitly through exposure to science concepts. reflective, providing students with iterative opportunities to test out, receive feedback, and revise their NOS ideas |
| 51 | (Schussler et al., 2013) p. 380 | In an ER approach, NOS learning objectives are made explicit to the students, who are provided with structured in- and out- of-class opportunities to reflect on their NOS understanding (ER activities). |
| 52 | (Schwartz & Crawford, 2004) p. 614 | The explicit approach advances that improving views of NOS should be planned for through objectives, instructional attention, and assessments. This approach intentionally draws learners’ attention to aspects of NOS through discussion, guided reflection, and specific questioning in the context of activities, investigations, and historical examples. The teacher provides learning opportunities, models performance, provides opportunity for practice, assesses student understanding, and provides feedback with reteaching as necessary. |
| 53 | (Sloane et al., 2023) p. 3 | In the explicit reflective approach, NOS is taught through purposeful integration of NOS tenets into the course. It is not enough for students to experience science; students must also learn about what it means to ‘do’ science and what it takes to gain scientific knowledge. This NOS integration requires an instructor to consider the context in which the instruction occurs, and researchers have demonstrated the value in embedding explicit, reflective NOS instruction across a context continuum. |
| 54 | (Voss et al., 2023) p. 1369-1370 | Nature of science instruction should be explicit. While it is important to accurately represent science in classroom activities, simple exposure to accurate depictions of science is not enough to help students develop more accurate ideas about NOS. For instance, simply engaging students in inquiry-based science learning has not been shown to lead to more accurate understandings of NOS. Rather, teachers must target NOS ideas as they would any other instructional objective in science. Teachers should include NOS in their planning, explicitly discuss NOS with students, and assess students’ NOS knowledge. Nature of science instruction should be reflective in nature. In tandem with activities that accurately represent science, reflective questioning helps students actively construct an understanding of NOS. Kim et al. (2005) wrote that effective NOS instruction requires, “NOS-specific pedagogical knowledge of making connections between what students do and what scientists do and between NOS and the conceptual structure of science content” (p. 29). Reflective questions may relate science and the work of scientists to students’ in-class experiences or explore students’ own sense-making about science. Goren and Kaya (2022) found that the use of metacognitive prompts is important for helping students develop an understanding of NOS. |
| 55 | (Voss et al., 2022) p. 1279 | An explicit-reflective approach, wherein NOS is treated as a learning outcome and planned for similar to other instructional objectives, has proved more successful in changing student conceptions of NOS. Explicit-reflective instruction should not be thought of as direct or didactic instruction. Khishfe and Abd-El-Khalick (2002) pointedly explain that the “explicit” in explicit-reflective, “should not be confused with didactic teaching. An explicit and reflective approach does not entail drilling students to reiterate certain generalizations about the nature of scientific knowledge.” (p. 554). Rather, Lederman et al. (2019) emphasized the student-centered nature of the explicit-reflective framework: we take for the term “reflective” to refer to the act of student contemplation, of mentally struggling with the meaning of their learning experiences. Thus, one might identify “reflective” teaching by asking if the instruction is student-centered and requires careful and extended thought (p. 201). |
| 56 | (Wan & Subramaniam, 2023) p. 1057 | Our study uses variants of the explicit-reflective approach to explore changes in NOS understandings of students – explicit in the sense that NOS attributes of interest are openly allowed to emerge. The roots of this approach can be traced to the tenets of constructivism and conceptual change. The explicit approach refers to teaching NOS directly through open discussions so as to reflect on some aspects of NOS. |
| 57 | (Wheeler et al., 2019) p. 4 | Explicit, reflective NOS instruction uses ‘instruction, discussion, and questioning…in the context of activities and investigation’ to focus student attention on targeted NOS aspects (Schwartz & Lederman, 2002, p. 207) |
| 58 | (Williams & Rudge, 2016) p. 412 | Explicit in this case refers to planned instructional practices that allow for NOS aspects to be openly covered in class. Reflective refers to students having the opportunity to come to their own conclusions about NOS aspects and not just repeating what the instructor tells them (Akerson et al., 2000) |
| 59 | (Witucki et al., 2023) p. 7 | Explicit refers to a teaching approach where the NOS concepts are discussed openly where students attention is drawn directly to the concept. Reflective refers to the student actively developing their own understandings based on explicit teaching. This explicit and reflective teaching approach provides the students with new knowledge and then allows for discussion and reflection to occur where students have the opportunity to either assimilate the new knowledge or create an accommodation to overcome a misconception. |
| 60 | (Yacoubian, 2021) p. 383 | In this study, explicit and reflective methods for teaching NOS were utilized. These methods assume the development of learners’ NOS understandings to be planned learning outcomes, where learners engage in reflective thinking, guided by their teacher, to deepen their NOS understandings (Khishfe & Abd‐El‐Khalick, 2002). |
| 61 | Zion et al., 2020, p. 1284 | ….requires explicit/reflective attention. Thus, instruction should be purposeful and guide the learners to reflect upon their experiences and relevant NOS or NOSI. The teacher must provide a learning experience (such as a historical episode, inquiry investigation, hands-on or conceptual activity) and then guide the learners to reflect upon what they have done in light of specific NOS or NOSI aspects. |