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Using the History of Research on DNA to Teach NOS

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Abstract
Science education literature states that fostering students' and teachers' knowledge of NOS has shifted from being a desirable goal to an essential one. This article focuses on the development of NOS conceptions among MA Education students. To develop those conceptions, the researcher designed various learning activities in the context of 'research of history on DNA'. Seven students were observed and audiotaped while working in groups in this classroom qualitative study. Before the intervention, pre-test on 'views on science'- Chen (2006) and group discussions held with participants indicated that their NOS conceptions were basic. After 7 sessions, a post-test was administered to students asking to justify NOS conceptions. These conceptions: scientific knowledge is tentative, laws are generalizations or universal relationships, theories are inferred explanations of nature; and that science is empirically based, socio-culturally embedded, and creative. Classroom discourses and responses to a post-test indicated that participants justified some NOS conceptions very well and some not so very well. It also argues that HOS offers potential for improved learning of NOS.

Keywords HOS · NOS · Research of history on DNA

Introduction

Nature of science (NOS) aims to discuss fundamental questions such as: what is science? What are the core characteristics (e.g., science relies on evidence, socio-culturally embedded, science is creative and self-corrective) of science? And what is the structure of scientific knowledge (e.g., hypothesis, law, and theories)? These questions deepen the learning of science content, helping students become critical consumers of the scientific knowledge that impacts their everyday decision making (Driver et al., 1996; National Research Council, 1996). For the past few decades, there has been a growing emphasis at the interface of pedagogies of NOS and understanding science (McComas, 2015; NGSS, 2013; OECD, 2017). In this context, sufficient research has been conducted on the effectiveness of different approaches to teaching NOS both in the general and specific disciplinary contexts of student learning (Dagher & BouJaoude, 2005).

Clough (2007) urges teachers to shift emphasis away from teaching the 'tenets of NOS' to question-based, for instance, to what extent scientific knowledge is tentative yet durable,

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stemming from his belief that students may memorise the tenets instead of developing informed understanding of NOS. Abd-El-Khalick (2012) attests to this, stating that instead of teaching tenets of NOS, teachers should build the understanding of NOS through the practice of diverse groups of scientists, this helps students gain authentic understanding of scientific knowledge generation and evaluation. In addition, a study conducted by Abd-El-Khalick & Lederman (2000) suggests that exposing pre-service teachers to history of science does enrich the views of NOS. Monk and Osborne (1997) argued that teachers must integrate history and philosophy of science to contribute to students' learning of science. The pedagogy of case histories proved to be effective for helping students understand the NOS (Adúriz-Bravo & Izquierdo-Aymerich, 2009; Howe, 2007; Rudge et al., 2014).

Dagher and BouJaoude (2005) stated that fostering students' and teachers' knowledge of NOS has shifted from being a desirable goal to an essential one. Erduran et al. (2007) noted that NOS helps teachers become more reflective and resourceful as a result they facilitate effective NGSS practices-based learning. Over the last few years, research has been conducted to understand prospective teachers' views about NOS to promote understanding of NOS (Garcıa-Carmona & Acevedo-Díaz, 2017). However, the review of literature done by Bugingo et al. (2024) reports that science content still has been communicated as a collection of facts rather than as a process in knowledge construction. The situation of NOS in India is very dire. Rai (2012) noted that in Indian Context:

> "NOS is overlooked from the pedagogical point of view. Rather, it will not be an exaggeration to state that there exists a very low level of awareness of NOS as is evident from the scarcity of the empirical studies on the pedagogies of NOS".

It is for this reason that teaching NOS through HOS is very important (Clough, 2018; Hodson, 2014; Lenning & Rudge, 2023; Van Dijk, 2014). The story of research on the history of DNA is a suitable means of showing how science progresses. Apparently, research in the history of DNA as a case exemplifies the "scientific inquiry" by shedding light on both the epistemic and non-epistemic aspects of science and points to the danger of scientific dogmatism. For example, the scientific method (model building) employed in the research of history of DNA is unique as opposed to the usually employed experimental testing and the gender issue around Rosalind Franklin helps students get some sense of non-epistemic factors involved in generating scientific knowledge (García-Carmona, 2021). Given the significance of case histories and the scope of research in history of DNA, the research questions that guided the study were the following:

1. What are MA Education science group students' ideas about the aspects of NOS before they are exposed to the intervention of the research on history of DNA?
2. What is the progression of those ideas after the intervention the MA Education students were exposed to?

Theoretical Framework

At the time when the substantive knowledge (e.g., interrelated concepts of a discipline) was given paramount importance, Kuhn (1970) and Schwab (1962) unequivocally advocated the integration of syntactic knowledge (e.g., interpretation of evidence, nature of scientific discovery, method and social embeddedness of science) into the science curriculum. Hereon, gradually the words "inquiry," "processes," and "structure" of scientific knowledge started gaining significance in the science education (Robinson, 1965).

To describe the aspects of NOS, a lot of models have been proposed, the first and highly cited one was 'consensus' model. According to this model there are some general aspects of NOS: science relies on empirical evidence; science is tentative yet durable; socio-culturally embedded; there is no step-by-step universal scientific method; structure of science (observation, inference, hypotheses, law and theory) and finally, that science is self-correcting (Lederman, 1992). In this context, Michael Matthews (2012), one of the pioneers of NOS, while acknowledging the breadth and diversity of the tenets proposed by 'consensus' view, he subjects it to critical scrutiny, concluding that the tenets of NOS proposed by Lederman need to be philosophically and historically informed for the benefit of teachers and students. As a way forward, he advocates a more relaxed, contextual, and heterogeneous 'Features of Science' (FOS) view. This view includes a consideration of values and socio-scientific issues, mathematisation, technology, explanation, worldviews and religion, theory choice and rationality, feminism, realism and constructivism over essentialist and epistemologically focussed NOS. Similarly, Hodson and Wong (2017) argue for the need of an NOS model, which authentically exposes students to the diversity of sub-disciplines in science and Allchin (2011) proposes 'whole science' model saying the aspects of funding, motivation, peer review, fraud, and others – need to be integrated.

Irzik and Nola (2013), further criticize the 'consensus' view of NOS for providing uniform view of science without being sensitive to the differences among scientific disciplines and missing out on the aims of science, and there being a mention of scientific method but with its details (e.g., inductive, deductive, abductive, and hypothetico-deductive method of testing) missing. The authors have proposed the 'family resemblance approach (FRA) which is a system of cognitive-epistemic and social-institutional aspects of science with a set of categories: (a) processes of inquiry, (b) aims and values, (c) methods and methodological rule, and (d) products. Further, Erduran et al. (2014) illustrated the application and potential of FRA for science education.

Although the aforementioned criticism of the 'consensus' view has been theoretical in nature, in recent years researchers started conducting empirical studies using the FRA model (Cheung, & Erduran, 2023). For example, in a 14-week study with 15 female pre-service participants, Kaya et al. (2019) reported that the Reconceptualised Family Resemblance Approach to Nature of Science (RFN) mediated teacher education intervention had an overall significant impact on pre-service teachers' views of NOS. In a similar study, Cullinane and Erduran (2022) argued that, after attending a 6-week RFN-based NOS workshop, the teachers have shown significant improvement on their NOS knowledge. Also, FRA has been adopted as a framework to investigate the content of science curricula, analysis of textbooks, development of instructional material and professional development resources in different parts of the world (see also Cheung & Erduran, 2023, for a review about empirical studies using FRA).

Although the researcher acknowledges the multiple models of NOS, given the wide acceptance of FRA model both theoretically and empirically, in the current study NOS was conceptualised as 'FRA', proposed by Irzik & Nola (2013) and Erduran et al. (2014).

Review of Literature

As noted in the "Introduction" section, the present study explores how some MA Education students who enrolled in an NOS course developed their conceptions of NOS in the context of research of history on DNA. Thereby, this section presents a literature review of the present study.

Teach NOS Explicitly

Khishfe (2014) & Cofré et al. (2019) have reported that both students and teachers have naïve conceptions of NOS. In addition, the naïve conceptions of NOS among preservice teachers are resistant to change (Mueller & Reiners, 2023). In this context, the literature of science education suggests that the sophistication of the conceptions of NOS is high when NOS is explicitly taught (Abd-El-Khalick & Lederman, 2000; Duschl & Grandy, 2013; Khishfe & Abd-El-Khalick, 2002; Khishfe, 2019, 2024; McComas & Burgin, 2020). This means that NOS should be explicitly dealt (García-Carmona, 2021).

Teaching NOS Through HOS

It is widely reported in the literature of science education that teaching NOS using HOS is highly recommended to critically reflect the interplay of epistemic and non-epistemic (social, political, economic and cultural contexts) factors in producing scientific knowledge at different space-temporal nodes. Conant (1947), in his book titled 'On understanding science: an historical approach', suggests that case histories: 1. shed light on new techniques and difficulties of experimentation; 2. examine the evolution of new concepts; 3. and, help the readers understand that science is an organized social activity. During the 1960s, Joseph Schwab (1962) advocated the process-based learning of science over product-based. Case histories are effective pedagogical tools to illustrate the process of modern science and enhance the understanding of the work of scientists (Nash & Conant, 1966). Brush (1974) went a step further and concluded that teaching science without using HOS may develop the 'whig view of history' and that will leave a wrong impression on the context of discovery.

Recent review of literature reported that the pedagogy of case histories is an effective means to extend and expand the learning of NOS (Abd-El-Khalick, 2012; García-Carmona, 2021). Nouri and McComas (2021) highlighted the HOS as a potential context for teaching NOS, upon interviewing 15 HOS instructors, the study reported that pre-service teachers learnt about NOS as a natural outcome of a HOS teaching.

García-Carmona (2021) used the historical case of Rosalind Franklin to reflect with pre-service elementary teachers on epistemic and non-epistemic obstacles faced by scientists. The study reported that pre-service elementary teachers have improved their understanding of epistemic and non-epistemic factors. However, the study emphasised the non-epistemic over epistemic factors.

Irwin (2000) in her action research with secondary grade students where control and experimental design was employed reported that 'historical case studies approach', challenges pupil's nomothetic image of scientific knowledge.

García-Carmona and Acevedo-Díaz's (2017) work on the controversy between Pasteur and Liebig on fermentation, reports that HOS narrative approach improved the epistemic as well as non-epistemic conceptions of prospective secondary science teachers of NOS'. Rudge et al. (2014) conducted a study where students were explicitly asked to reflect upon several NOS issues in the context of industrial melanism. The survey results suggest that the NOS views of participants transformed for some issues. A pedagogical method involving a film presentation about the discovery of radium by the Curis, improved prospective teachers' views on the role of gender in science (Adúriz-Bravo & Izquierdo-Aymerich, 2009).

Therefore, the use of HOS helps students not just to explicate epistemological, ontological, and sociological questions in science, but also fosters their explanatory power with respect to the concepts that are at the interface of science, society, and culture (Justi & Mendonça, 2016; Koliopoulos et al., 2007; Maienschein et al., 2008). Several studies have also echoed the same stating HOS is ideal in exemplifying the progress of science and thus helps in comprehending characteristics of NOS (García-Carmona & Acevedo-Díaz, 2017; Clough, 2011; Gooday et al., 2008; Irwin, 2000; Adúriz-Bravo & Izquierdo-Aymerich, 2009; Koliopouloset al., 2007; Matthews, 2015).

The Status of NOS in India

In alignment with the prevailing NOS-HOS scholarship discussed in the previous section, India's National Curriculum framework (2005) and position paper of the National Focus Group on Teaching of Science (2006) recommended that "process and historical validity" is important in teaching of science. Process validity helps to understand the generation and validation of scientific knowledge, whereas historical validity enables the learner to appreciate the formation of ideas in science. It keeps the learner informed that knowledge making and holding is a social process. The significance of NOS in science education has been well established with a robust justification, for years. However, the recommendations of the policies are not translated into classroom practice in India and the emphasis given to NOS in science classrooms is not so prolific (Rai, 2012). Similarly, another study by Singhal (2017) claims that most of the pre-service students as well as teacher educators failed to distinguish the idea of a law from a theory. Kaur (2019) in her work titled "Textual Texture of School Science", argues that the science textbooks mention the scientist's names for students to remember as a fact but not the story behind the discovery. Apparently, the situation of classroom practice of NOS in India is at a very nascent stage, thus it is vital to support prospective science professionals in acquiring the knowledge of NOS (García-Carmona, 2021).

From the review of literature, it is evident that experimental studies conducted to understand the effect of HOS on the understanding of NOS are very scanty. There are a very few studies of action research done in the context of HOS and NOS, though. Moreover, the research on NOS in India is at a very nascent stage. Given the need for explicit teaching of NOS, in the present study, the researcher developed learning material in the context of history of DNA to explicitly teach the aspects (both epistemic and non-epistemic) of NOS. The learning activities were also specifically designed to help the participants critically reflect on the aspects of NOS (Clough 2011a). Therefore, the current study is set to understand the potential of 'research of history on DNA' in fostering students' understanding of NOS.

Methodology

After reading the documents of 'stories behind science' published at National Science Foundation (NSF) website, the researcher was inspired to conduct a classroom study (action research) employing the topic 'Model Building: Piecing Together the Structure of DNA' written by Blair Williams and colleagues, to improve the understanding of NOS of MA Education students. During the first semester of MA Education, the MA

Education students receive instruction on the basics of education through their core courses (e.g., philosophy of education, sociology of education, child development and learning, and Indian school systems). In the second semester students learn about the focus area courses (e.g., science education, mathematics education, language education, and social science education) before going to teach as part of their field practice – 3. There are four courses in science education: pedagogy of science, nature of science, pedagogical content knowledge of science and curriculum material development in science. Nature of Science in science education covering approximately 35 teaching hours, of which 15 teaching hours were budgeted for this study. The researcher made observations of classroom discussions and the same was also audiotaped over 9 sessions of 1.5 hours each. The research methodology of the study was qualitative, pretest and posttest design was employed to see the progression of NOS conceptions of the participants. While there was a study (García-Carmona, 2021) conducted in the context of the historical case of Rosalind Franklin that focussed more on the non-epistemic aspects of NOS, the current study facilitated the learning in the context of 'research on the history of DNA' where Rosalind Franklin is one of the episodes of research on history of DNA and aimed to equally foster both epistemic and non-epistemic factors.

Sample

The participants of the study were seven MA Education students (5 women and 2 men) of ages from 23 to 37 years at Azim Premji University, India. The students enrolled in an NOS course (one of the science education courses) come from science undergrad background and from diverse socio-economic backgrounds. The details about the participants are summarized in Table 1.

Intervention of the Study

Upon taking the written consent from the students and clearance of Institutional Review Board (IRB), the pre-test of '*views on science questionnaire'* (Chen, 2006) was administered to understand the students' initial conceptions of NOS along with an informal discussion. The test-retest reliability of the tool is high with correlation coefficient, 0.82. Each question of this questionnaire starts with a statement about the conception of NOS. Participants responses of the statements on a five-point Likert scale (strongly agree, disagree, undecided,

Table 1 Details of the participants

Name	Gender	Age	Education background
S1	Female	23	Bachelor of Engineering
S2	Female	23	Bachelor of science and Bachelor of Education (BSc. B.Ed). Four-years integrated teacher preparation programme.
S3	Female	23	Bachelor of science (Specialisation in zoology)
S4	Female	30	Bachelor of Engineering (She also has the teaching experience at school)
S5	Female	37	MSc in pharmacy (She also has the teaching experience at school)
S6	Male	24	Bachelor of science (Specialisation in physics)
S7	Male	26	Bachelor of science, MSc in chemistry, Bachelor of Education.

agree and strongly agree) are provided in the Table 2. While students were asked to respond to the 5-point Likert scale in the pretest as shown in the Table 2, the students were asked to descriptively justify the NOS conceptions in the context of research on the history of DNA on posttest. The reason, the author believed for asking students to descriptively justify the conceptions of NOS on posttest was that during the intervention, students had the scope to acquire the ability to illustrate the NOS conceptions but the that wasn't the case before the intervention as found both in the pre-test and in an informal discussion.

During the instruction, the participants were engaged in several in-class activities to illustrate the epistemology of science and conceptions of NOS. The learning activities (see Table 3) designed in the context of history of DNA were implemented during this intervention. Every session conducted was activity-based, in the first four sessions, the students were asked to identify the epistemic aspects in the context of research on history of DNA: hypothesis, inference, and additional evidence (See Fig. 1) and the students also have developed an argument using Toulmin Argument Pattern (See Fig. 2). There was a lot of discussion on what constitutes as a particular epistemic practice, for example why some thing is a hypothesis but not a theory. In the 7th and 8th sessions, for four hours we have dived deeper into the structure of knowledge (e.g., hypothesis, law, and theory) and the non-epistemic aspects of science, the question discussed during these sessions are described in the "Results" section with classroom discourse (see Results section for the questions discussed). The pedagogies employed for these sessions include class discussions, group work, individualized activities, relating classroom science to everyday life, teaching using TAP, exemplification of scientific inquiry and argument driven inquiry in the context of research on history of DNA.

Data Analysis

The data were analysed in different stages. The pre-test data collected through Chen (2006) questionnaire were analysed before the intervention, the classroom interaction was analysed throughout the intervention, and the post-test descriptive responses were analysed after the intervention. The researcher engaged in deductive coding for the themes: science relies on empirical evidence, scientific method, structure of scientific knowledge, social embeddedness of science (e.g., gender, culture, theory ladenness, funding, objectivity). The incorrect responses were categorised as naïve, and the correct responses as intermediary and the correct responses with illustrations as informed. For example, if a participant says 'there is NO step-by-step scientific method in science' as seen in the context of the research on the history of DNA, and further argued that the scientists followed 'model building' instead of experimentation method. This was treated as the informed understanding of the NOS aspect. Similarly, the artifacts with illustration developed by the students during the teaching learning process are seen as the informed understanding of NOS, in the absence of illustration, it was intermediary. Same technique was employed for the post-test responses analysis too.

Results

Pre-Test Response Analysis

The summary of *Pre-test* and group discussion results indicated that students have a naïve understanding of many conceptions of NOS while intermediary understanding of a couple

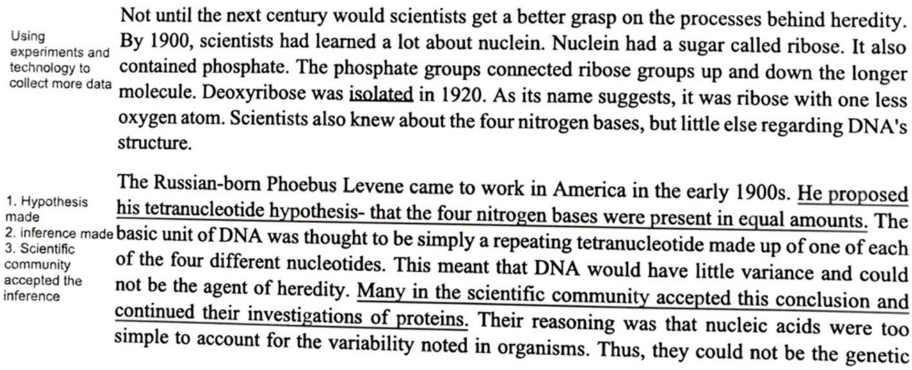
Table 2 Responses of students on 'views on science' (Chen, 2006)

		SA*	A*	U*	D*	SD*
Scientific method						
1	The scientific method ensures valid, clear, logical, and accurate results. Thus, most scientists follow the universal method in research	1	4	2		
2	Most scientists use the scientific method because it is a logical procedure	1	5	1		
3	No matter how the results are obtained, scientists use the scientific method to verify it	1	5	1		
Views on a law						
1	Theories are not as definite as laws	1	3	1	2	
2	If a theory stands up many test (improper sentence) it will eventually become a law, therefore, a law has more supporting evidence	1	2	3		1
3	Some theories have more supporting evidence, than laws		2	3		2
Imagination in scientific investigation						
1	Imagination is not consistent with the logical principles of science	1		3	2	2
2	Imagination may become a means for a scientist to prove his point at all costs	1		3	1	2
3	Imagination lacks reliability	1	2	2	2	
Influence of society & culture on scientific investigation						
1	Scientists with good training will remain value-free when carrying out research		2	2	2	1
2	Science requires objectivity, which is contrary to the subjective socio-cultural values	1	3	1	2	
Scientist's beliefs are influenced by personal beliefs						
1	Through scientific training scientists can abandon personal values to conduct objective observations		2	5		
Observations are independent from theories						
1	Observations will be the same because observations are exactly what we see	1	1	3	1	1

*SA**-Strongly agree; *A**- Agree; *U**-Undecided; *D**-Disagree; *SD**- Strongly disagree. The values in the cells are the number of students who opted a particular position on the Likert scale

Table 3 Summary of the Intervention

Day	Activity	Purpose
1	Pre-test: Test of '*views on science questionnaire*' (Chen, 2006).	
Teaching epistemic practices in the context of research on the history of DNA using Inquiry model, and Toulmin argumentation pattern (TAP).		
2&3	Identification and discussion of epistemic practices in the context of research on the history of DNA	The epistemic practices identified by the students are shown in Fig. 1.
4&5	Theory of the structure of DNA in the form of TAP	Students have developed argument for the structure of DNA using TAP (see, Fig. 2)
6	Is the discovery of the 'double helical structure of DNA' a theory?	To teach aspects of scientific knowledge (hypothesis, law, and theory)
Teaching non-epistemic aspects of NOS in the context of research of history on DNA		
7&8	Discussion on non-epistemic aspects of NOS using questions developed in the context of research of history on DNA.	Students critically reflected non-epistemic aspects of NOS in the light of the questions presented in "Classroom Interactions Analysis" section.
9	*Posttest: Students are asked to descriptively justify the conceptions given in the questionnaire* (Chen, 2006).	



Using experiments and technology to collect more data

Not until the next century would scientists get a better grasp on the processes behind heredity. By 1900, scientists had learned a lot about nuclein. Nuclein had a sugar called ribose. It also contained phosphate. The phosphate groups connected ribose groups up and down the longer molecule. Deoxyribose was isolated in 1920. As its name suggests, it was ribose with one less oxygen atom. Scientists also knew about the four nitrogen bases, but little else regarding DNA's structure.

1. Hypothesis made
2. inference made
3. Scientific community accepted the inference

The Russian-born Phoebus Levene came to work in America in the early 1900s. He proposed his tetranucleotide hypothesis- that the four nitrogen bases were present in equal amounts. The basic unit of DNA was thought to be simply a repeating tetranucleotide made up of one of each of the four different nucleotides. This meant that DNA would have little variance and could not be the agent of heredity. Many in the scientific community accepted this conclusion and continued their investigations of proteins. Their reasoning was that nucleic acids were too simple to account for the variability noted in organisms. Thus, they could not be the genetic

Fig. 1 Identification of epistemic practices in the context of history of DNA

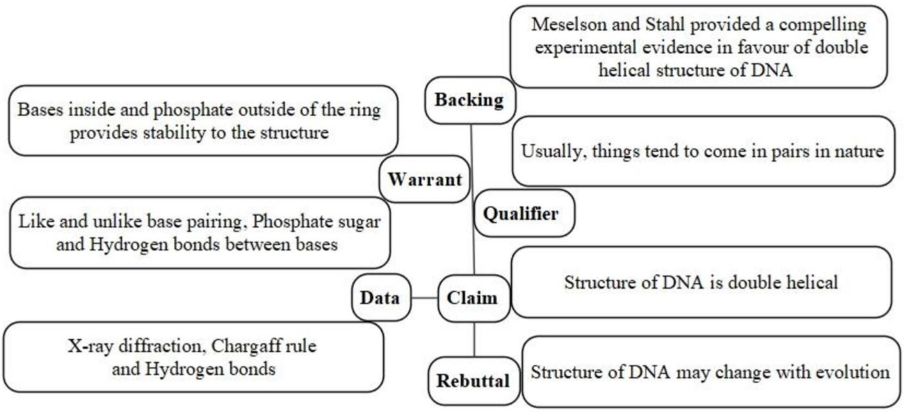


Fig. 2 Double helical structure of DNA presented in the form of Toulmin argument pattern

of conceptions. For example, the naïve conceptions include ‘scientists employ step by step universal method’, ‘laws are more definite’, ‘theory becomes a law if it stands up to many tests’, ‘imagination is at odds with science’ and ‘observations are not theory laden’. The students held an intermediary conception of NOS - ‘socio-cultural values do influence the objectivity of science (see Table 2 for the student responses).

Following the pre-test, the group discussion was held in the same session to discuss their responses on the ‘views on science’ (Chen, 2006) before the intervention. During this discussion it was found that students didn’t know the meaning of ‘empirical evidence’ owing to their regional language background. It was also observed that students did not have the knowledge of the difference between a scientific theory and a law. However, students believed that law is more powerful scientific knowledge than a theory. When asked to explain, how laws were powerful, students responded that:

> “Laws won’t change, for example, Ohm’s law, while theories change, for example, the atomic model changed from Rutherford’s model to Neil Bohr’s theory.”

> "Students believed that society does affect the production of scientific knowledge drawing on their knowledge of 'caste' but could not explain with examples. 'Caste system' is a graded hierarchy observed in India."

Post-Test Response Analysis

A *post-test* after eight sessions was conducted asking students to descriptively justify the NOS conceptions in the context of the research of history on DNA. Students' answers of the post-test are provided below:

Views on '*scientific knowledge is empirically based*': all the students described that science relies on empirical evidence with illustration, but one student could not provide an illustration. Following are the responses from the students:

> "Taking the case of the history of DNA, "X-ray diffraction image served as the empirical evidence" for the double helical structure of DNA."

> "Even though the scientific community was inclined to the tetra-nucleotide hypothesis, the scientific community had to accept Chargaff's proposal as it had empirical evidence collected by him. This shows that science secludes supernatural elements in the production of scientific knowledge."

> "Even after the double helical model was accepted by the scientific community, further work was done by Mathew Meselson and Franklin Stahl to experimentally prove the double helical model of DNA. This shows that scientific knowledge is empirically based."

Views on '*scientific knowledge is tentative yet durable*': six out of seven students could explain scientific knowledge is tentative yet durable in the context of the history of DNA. Students argued that science is durable as it relies on empirical evidence, however bound to change in the light of new evidence.

> "In the early 1900s Levene proposed the tetra-nucleotide hypothesis: four nitrogen bases are present in equal amounts. But Chargaff has been sceptical about this hypothesis, and proposed A=T and G=C rule in 1948. It took more than forty years to disprove tetra-nucleotide hypothesis" (Students argued that tetra-nucleotide hypothesis believed to be true until new evidence unearthed by Chargaff)."

> "From the content of the history of DNA, it can be said that the knowledge of DNA as the double helix structure is also subjected to change if there arises new evidence for any other structure. But till the new evidence emerges the knowledge is durable."

Views on *'Creativity'*: students did agree that imagination is vital in the process of scientific knowledge generation. However, many students could not illustrate how creativity really operates in the process of generation.

> "Rosalind Franklin put A-form DNA in 70–90 percentage of humidity for DNA to open a bit named B-form. Imagination is key for this to happen."

Views on *a 'Law'*: there were only two students out of seven attempted to explain what laws are, after having discussion with the students on why they found it difficult to illustrate the characteristics of a scientific law, students responded that "they needed sound content knowledge to illustrate scientific law better.

> "Laws, according to me it's all about universal, measurable, with empirical regularities that are experimental and observable through senses. It is also reproducible everywhere."
>
> "Laws describe the relationships between variables related to some phenomena in the natural world. For example, Ohm's law describes the relation between voltage and current under certain conditions."

Views on '*scientific knowledge is socially and culturally embedded*': It is evident from the responses of the students on the conception of 'scientific knowledge is socio-culturally embedded, that students have illustrated theory ladenness, gender bias, and socially influenced hypotheses in the context of research of history on DNA quite well. Following are the responses

> "I strongly agree that scientific knowledge is socially and culturally embedded. In the context of gender Rosalind was a woman, she contributed to the finding the structure of DNA successfully but still she did not get the Nobel Prize."
>
> "A lot of scientists were inclined to believe in the idea of three helical structures of DNA proposed by Linus Pauling as he was already popular for the discovery of the structure of protein. It shows that science is socio-culturally embedded."
>
> "Watson and Crick may be the most well remembered scientists who worked on the structure of DNA, but they couldn't have succeeded without a large supporting cast."

Views on 'theory': It is evident from the posttest responses that the participants have sufficiently understood what a scientific theory is. However, the students also invoked the concepts outside the history of DNA to illustrate the concept of a theory.

> "Theories are explanations of some aspects of the natural world. It also helps in making predictions. Big bang theory is supported by the 2nd law of thermodynamics. Kepler laws support the theory of gravitation."
>
> "The double helical structure of DNA is more a theory. DNA is responsible for heredity of some characteristics from one generation to next generation."

Students described that theory is an overarching explanation of natural phenomena, this invokes laws, facts and inferences. Students also mentioned that theories do have predictive power.

Classroom Interactions Analysis

Epistemic Practices On day 2&3 the students were acquainted with the epistemic practices of science (see Fig. 1). This activity helped students get some sense of the epistemic aspects of NOS (e.g., observation, empirical evidence, hypotheses, & inference).

Views on '*there is no single universal step-by-step scientific method*': It is evident from the excerpt of the classroom conversation that students developed a well-informed conception of 'scientific method' in science.

Facilitator: What was the method employed to discover the double helical structure of DNA?
S1: Scientific method.
Facilitator: What is a scientific method?
S1: Systematic collection of data and testing the hypothesis.
Facilitator: Did Watson and Crick test the double helical structure of DNA?
S2: No.
Facilitator: Then, what do you think is the method employed by Watson and Crick?
S2: By building the model…
Facilitator: How did they arrive at this model?
S3: Hmmm… through trial and error.
S4: They have also used the results produced through experimentation.
Facilitator: So, do you think we have the 'universal scientific method'?
S2: No, because scientists do not strictly follow the Hypothetico-deductive method… In fact, in the discovery of the structure of DNA, the scientists used model building…

Views on *a 'theory'*: During the classroom discussion, students illustrated the idea of 'scientific theory' in the context of double helical structure of DNA (see Fig. 2).

Facilitator: So now, tell me, 'Is the discovery of the structure of DNA a law or a theory?
S5: It is a theory because as I already said, it takes the laws of chemistry and biology to explain the structure of the DNA.
Facilitator: What do you mean by the laws of chemistry?
S5: The hydrogen bonds between the nitrogen bases. Chargaff rule.
Facilitator: Hmmm.... Any more responses on this question?
S4: Yes, it is a theory because it explains how the DNA and genes are made.
S5: It also helps to make predictions using the structure of DNA and useful for genetic engineering…
S4: The structure of DNA also explains the production of GM crops.
S2: It is not a law because it is not universal like a law, and it does not describe the relationship between two variables like it happens in the case of Ohm's law.

The following three questions were employed to critically reflect upon the **non-epistemic aspects** of NOS.

1. Despite the growing evidence favouring DNA - genetic material, scientists preferred to believe that genes were protein molecules. The reason scientists claimed was that DNA does NOT have sufficient complexity to be the genetic material like protein does. What do you say about the character of science from this? *(One of the NOS aspects this question focussed was theory ladenness)*

Facilitator: I will slightly reframe my question in this context, when student A says that you need sufficient evidence to accept something as truth particularly in science. What is the evidence that the scientists had to believe protein as genetic material?
S3: Hmm…Experiments?
Facilitator: What experiments do they have?
Facilitator: anybody?
S4: My point is why scientists think DNA should be as complex as protein to be a genetic material. Maybe less complex, but they are pre-assumed that it is complex without having any evidence.
Facilitator: Don't you think the scientists are sticking to the idea of triple helical structure as it is believed by an eminent scientist Linus Pauling?
S5: Yes. Because protein structure was established by a very big person by name Linus Pauling, the other persons of the community also believed that yes, genetic material should be a protein. (theory ladenness)

From this discussion, it is visible that students got the sense of the influence of theory ladenness in the process of construction of scientific knowledge.

2. A major advance came when Rosalind Franklin developed a new way to image DNA. Prior X-ray diffraction was done on a "crystalline" form of DNA (A form). Franklin determined that if she put the DNA in an environment of 70–90% humidity, the DNA opened up a bit (B form). When the B form was subjected to X-ray diffraction, the resulting image was interpreted as clearly indicating a helical structure. Which element of the science does this reflect? (*science demands imagination, interpretation of the data*)

S4: Manipulation, actually, DNA was A form. So, putting in that humidity caused the change of its form.
S2: Imagination.
S6: Thinking out of the box.

3. Scientific journal articles that announced the structure of DNA provided evidence in support of the final structure. The missteps, personalities of participants, and significant interactions between individuals are left out of textbooks. How does leaving out that information result in science students having misconceptions? *(socio-cultural factors do influence in the development of scientific knowledge)*

S5: We are going through the products, not the whole process of how it came.
S2: Textbooks give only information.
Facilitator: So, you're saying that textbooks focus only on the information not on the progression of the ideas?
S7: In the textbooks only, some information is given but not the full story. Here Watson and Crick are given more importance, *Rosalind Franklin was left out. It gives the impression that only a set of people can become scientists. We science students if we introduce science like this, students get the feeling that those who have the privilege can become a scientist otherwise, we are not suitable for that so, from the budding stage itself we are nipping the curiosity.*

S3: What is written in the textbook, it is taken as granted, there is no scope that it can be wrong.
S4: So, here I get one value - appreciation, if you are taking someone's things you must appreciate them. You must appreciate what others have done. In our textbooks also it should be there so we can know the story behind the scenes.
S5: Adding to that, I *have just been through the NCERT textbook, I found only Watson and Crick and no mention of Franklin and Wilkins. Somehow, textbooks are disregarding the contribution of others. If you see from a gender perspective, textbooks are disregarding Rosalind Franklin, it is giving the impression that only men can be scientists.*

From the above classroom conversation, students report that the science textbooks of India present concepts in the form of facts but did not include the journey behind the discovery of those concepts. The students perceived that it is boring to read only the product of science. They also argued that the case of Rosalind Franklin should be part of the text when discussing the structure of DNA.

Overall, it is apparent from both the classroom discussions and post-test that the students could justify the conceptions of NOS. Students also described the difference between a law and theory but found it difficult to provide robust examples of a scientific theory. In a similar vein, it is evident from all the students' responses that they understood, creativity is vital in doing science, yet some found it challenging to explain with examples. Thus, this study reports that students have developed informed understanding of epistemic and non-epistemic aspects of NOS.

Discussion

This study documents how MA Education students who enrolled in an NOS course developed their understanding of NOS in the context of research of history on DNA. Before the intervention students displayed naïve conceptions of NOS (see Table 2 for student responses). These NOS conceptions of students are consistent with the existing literature and attest to the point of nomothetic image of science (Wahbeh & Abd-El-Khalick, 2014, Abd-El-Khalick & Akerson, 2004, 2009, Rai, 2012). The group discussion held before the intervention indicated that students had naïve conceptions of a scientific theory and a law, the same was reported by Singhal (2017) among pre-service students as well as teacher educators in India.

During the intervention, students were introduced to the concepts like epistemic practices, and language of scientific method (see Table 3 for more information). Post these sessions, students have identified epistemic practices in the context of research of history on DNA and formed the argument of double helical structure of DNA (see Figs. 1 and 2 respectively). It is evident from these two activities that students could illustrate the epistemic practices and elements of TAP. The results of the present study report that students displayed an informed understanding of a few conceptions of NOS. It is evident from the science education literature that knowledge of NOS has become an essential goal from being a desirable goal. The existing literature (Adúriz-Bravo & Izquierdo-Aymerich, 2009; Irwin, 2000; García-Carmona, 2021; García-Carmona & Acevedo-Díaz, 2017; Niaz, 2009), reported that students formed informed conceptions of NOS when explicitly taught in the context of research of history on DNA.

About the understanding of a law and a theory, during the classroom discussion, the students did explain the difference between a law and a theory but in the test conducted after the intervention, it was found that students struggled to illustrate in the context of research of history on DNA. The existing literature also reports that the students found it difficult to form a sound conception of a law and a theory as it required in-depth content knowledge (Cofré et al., 2019; Wahbeh & Abd-El-Khalick, 2014). The questions discussed on day 7&8, helped students critically reflect on non-epistemic conceptions of NOS. The case of Rosalind Franklin was invoked by students to illustrate the non-epistemic conception in science (e.g., gender bias), same was reported by García-Carmona' (2021) where he argues that NOS must emphasise non-epistemic (social, cultural, psychological) aspects at the same level as epistemic aspects of NOS. Students stated that societal factors do have influence on the generation of scientific knowledge (e.g., triple helical DNA hypothesis widely believed as it was proposed by a successful scientist named Linus Pauling despite of the lack of evidence). Valencia et al. (2023) stated that students' understanding of some of the aspects of NOS improved more easily than others, the present study also attests the same. Similar findings were found in the literature of NOS stating explicit instruction of NOS in the context of HOS helps in developing the understanding of NOS (Abd-El-Khalick & Lederman, 2000; Duschl & Grandy, 2013; Khishfe & Abd-El-Khalick, 2002; McComas et al., 2019). However, research also provides evidence that even the explicit approach is not sufficient to transform all the learners' naïve conceptions of NOS into informed ones (Khishfe, 2008). Students, while responding to the question 'what does leaving out the information about the missteps, personalities of participants, and significant interactions between individuals result in regarding how science and scientists work? The students strongly argued that the journey behind the discovery of a scientific idea should be a part of the science textbooks as it truly helps to understand the role of sociological, psychological factors in the production of scientific knowledge, thus resulting in a comprehensive understanding of science.

Implications & Limitations

The study leads to several implications related to the teaching and learning about NOS. The findings of the study accentuate the significance of HOS as a context to develop NOS aspects of pre-service and practicing teachers and thus in turn can promote teaching learning of NOS at school. At the same time, explicit instruction on epistemic and non-epistemic aspects of NOS can make teachers reflective practitioners of science. The practitioners can implement the intervention discussed in the present study in their classrooms to teach aspects of NOS. Finally, the author believes that the research of this kind may motivate other researchers to take up NOS related research as it is not very prolific in India. However, the findings have the following limitations:

- The instructor was the researcher too, but as mentioned in the methodology sufficient care was taken to avoid the researcher's bias while analysing the data and during the classroom discussions.
- For the pre-test 'views on science' Chen (2006) was employed to examine the students' conceptions of NOS (see Table 2), but for the post-test, the researcher asked students to descriptively justify the same conceptions of NOS. The reason behind doing this was to know the students' deeper understanding of NOS through illustrations. The researcher

did not do this for the pre-test as students' understanding of the statements of NOS itself was very naïve.

- Students found it challenging to articulate their knowledge both in written and spoken owing to their regional language mediums.

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