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Developing Student Teachers' Conceptions of the Nature of Science: An Assessment of a Pre-service Science Teacher Programme in Tanzania

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The importance of enabling student-teachers to acquire informed conceptions of the Nature of Science (NOS) is widely emphasised. Hence, this study investigated the effectiveness of a science pre-service teacher education programme of one university in Tanzania in enabling student-teachers to acquire informed conceptions of NOS as stages in a Learning Progressions model. We employed a comparative impact study design where NOS conceptions were compared resulting from two interventions—science student-teachers trained in inquiry-based learning (IBL) ($N = 154$) and those trained in IBL plus a NOS course ($N = 86$). The first teacher education programme emphasises learning through IBL, thus assuming that students will automatically acquire NOS conceptions through experiencing IBL. The additional NOS course targets explicit instruction of three NOS aspects, i.e. the tentative nature of scientific investigations, the scientific method and scientific theories and laws. Moreover, non-science student-teachers were used as a baseline control group ($N = 106$). Findings indicated that generally student-teachers had limited conceptions of NOS, implying serious gaps in NOS learning progression. Neither experiencing IBL nor being trained in an additional NOS course had significant impact on student-teachers' understanding of NOS. Largely, our findings imply that the pre-service science teacher programmes are not sufficiently enabling student-teachers to acquire informed conceptions of NOS, a condition that calls for immediate intervention. We recommend a comprehensive review of the NOS progression. In the meantime, for the pre-service education programme we recommend a stand-alone and compulsory NOS course that explicitly addresses all of the aspects of NOS.

Keywords: *Nature of science; student-teachers; science teacher education; Tanzania*

Introduction

The importance of enabling students and teachers to be knowledgeable about the Nature of Science (NOS) is widely emphasised (Kite et al., 2021; Librea-Carden et al., 2021; Vhurumuku, 2010). There are several reasons for this. Mainly, understanding of NOS is said to influence how science is interpreted, accepted and conducted (Lederman et al., 2013). That is to say, conceptions of NOS are associated with one's faith in science and how it should be conducted. Furthermore, informed conceptions of NOS are associated with a positive attitude towards science (Das et al., 2019), students' skills to conduct scientific investigations (Khishfe, 2021), motivation to engage in scientific inquiry (Leden & Hansson, 2019) and students' understanding of science concepts (Michel & Neumann, 2016). Generally, NOS is so fundamental that understanding it entails being aware of the values and beliefs about scientific knowledge, its legitimacy and how that knowledge should be produced (Lederman et al., 2013). Although what constitutes NOS has tended to vary across cultures (Das et al., 2019; Lederman et al., 2013), there are aspects of NOS that are agreed upon in the literature.

In the context of school science, there has been the intention to equip teachers with informed conceptions of NOS so that they can effectively teach science subjects (Librea-Carden et al., 2021; Kite et al., 2021; Linneman et al., 2003). Efforts to equip teachers with informed conceptions of NOS have tended to begin as early as during pre-service teacher preparations (Librea-Carden et al., 2021; Sumranwanich & Yuenyong, 2014; Vhurumuku, 2010). Nonetheless, how best NOS conceptions can be developed among learners remains unresolved. One body of literature argues that learners who are exposed to inquiry-based learning (IBL) can automatically develop NOS understanding (Das et al., 2019; Duschl & Grandy, 2012). However, this approach has been attacked for being less effective. For instance, there is evidence that student-teachers tend to have flawed conceptions of NOS (Librea-Carden et al., 2021; Vhurumuku, 2010), which might signify flaws in teacher preparation programmes even though these may promote IBL. The alternative perspective emphasises explicit curricula and instructional strategies that deliberately aim to teach the NOS (Khishfe, 2021; Nouri et al., 2021). In this case, the aspects of NOS can either be taught as a stand-alone topic or situated within teaching a particular science topic (Bell et al., 2011). Several empirical studies have concluded that these approaches to NOS instruction enhance student-teachers' understanding of NOS when compared with implicit instruction (Bell et al., 2011; Vhurumuku & Chikochi, 2017). It is important to note that explicit approaches to NOS instruction have taken many forms. For instance, Khishfe and Abd-El-Khalick (2002) enhanced NOS conceptions using an additional follow-up classroom discussion about NOS tenets (tentative, empirical, inferential and imaginative and creative) for the experimental group that engaged in similar inquiry activities with the control group. Also, Vhurumuku and Chikochi (2017) found that pre-service teachers who were taught the principles of scientific literacy, history of science, philosophy of science and sociology of science, and strategies of teaching NOS outperformed those who were solely taught the basic NOS tenets and strategies for teaching NOS only. According to McDonald (2010) combining explicit teaching of NOS with implicit argumentation strategies enhances NOS conceptions among student-teachers. In his case, explicit NOS instruction involved three tenets of subjectivity, tentativeness and the empirical basis of science. Moreover, according to Khishfe (2021) gains in school students' NOS conceptions were far better when instruction about argumentation was made explicit.

Context of the Study

While secondary school curriculum documents in Tanzania advocate IBL (Ministry of Education and Vocational Training, 2007, 2009a, b), the learning of NOS is less emphasised (Kinyota & Kavenuke, 2018). Instead, it is assumed that students will acquire NOS conceptions automatically as they engage in IBL (Das et al., 2019). Unfortunately, teacher-centred approaches continue to dominate in science classrooms in Tanzania (Kafyulilo & Tilya, 2019), making it rare for students to engage in IBL. This raises a possibility of student-teachers joining pre-service teacher programmes with naive conceptions of NOS. More significantly, in a context where teachers have very little access to professional development opportunities (Kinyota et al., 2019), pre-service teacher education programmes in Tanzania constitute the right place for nurturing teachers' conceptions of NOS. Unfortunately, there is a paucity of studies on student-teachers' conceptions of NOS in Tanzania, especially on the effectiveness of pre-service programmes in developing required NOS conceptions. Since earlier work (e.g. Das et al., 2019) has concluded that conceptions of NOS vary across cultural and social contexts, previous findings about effective ways of developing pre-service teachers' understanding of NOS may not apply in Tanzania. Given the scarcity of research on this subject in Tanzania, this study was deemed necessary.

Pre-service science teacher education programmes at university level aim to educate teachers in science and mathematics. Student teachers majoring in science not only continue studying science content, but also take science pedagogy courses that are meant to enable them teach science effectively. As part of science content, student-teachers majoring in science specialise in one or two subjects—physics, chemistry, biology and mathematics. These subjects are taught theoretically and practically, where science students spend three hours conducting scientific investigations in the

laboratory every week. Each student has at least three courses per semester from his/her subject of specialisation (e.g. physics), making a minimum of 810 hours of laboratory practical sessions upon programme completion. Laboratory sessions emphasise IBL skills such as framing questions, designing and conducting investigations, communicating results, and making conclusions.

Before joining the university, science student-teachers are expected to hold some conceptions of NOS gained during the six years of secondary education. Although the aspects of NOS are not explicitly addressed, their science pedagogy courses emphasise learning science through IBL (Kinyota & Kavenuke, 2018). The three-year programme consists of five science pedagogy courses, making a total of 125 lecture hours and 75 seminar hours. Thus, not only are the courses taught through IBL, they also aim at enabling student-teachers to teach science using IBL (Kinyota, 2020). In this case, IBL skills are both taught as stand-alone topics and integrated into specific science content. Therefore, student-teachers majoring in science are expected to hold informed conceptions of NOS as a result of experiencing IBL. We considered these student-teachers with experiences in IBL as intervention group 1. Furthermore, one department in the college offers an optional course called 'scientific methods' to second-year students. The course has a total of 45 lecture hours and 15 seminar hours. According to the course syllabus, students are expected to be able 'to demonstrate knowledge on the Nature of Science, designing scientific investigation, and write scientific research proposals, report, summarise and interpret data correctly'. Further, students learn about NOS aspects of the tentative nature of scientific investigations, the scientific method and scientific theories and laws. These NOS aspects are taught as stand-alone sub-topics. Thus, students who were trained in the course can be considered as science majors with an additional intervention element, intervention group 2. This study intends to investigate the effectiveness of the pre-service science teacher education programme in enabling students to acquire informed conceptions of NOS. In this case, science majors with experience in IBL and those who took an additional course on NOS serve as two experimental groups, while non-science majors represent the NOS conceptions of secondary school or the pre-intervention control group.

Specifically, this study was guided by the following research questions:

1. What are the conceptions of NOS held by science student-teachers trained in IBL vs. those trained in IBL plus a NOS course, and by non-science student-teachers?
2. How does the understanding of NOS of science student-teachers with experience of IBL differ from the understanding of NOS of non-science student-teachers?
3. How does the understanding of NOS of science student-teachers with experience of IBL differ from those with an additional NOS course?

The study will inform policy and practice of science teacher education in Tanzania.

The Aspects of NOS

The lack of agreement regarding what constitutes NOS is widely acknowledged. What constitutes conceptions of NOS has tended to change over time (Lederman et al., 2013) and vary across contexts (Das et al., 2019). Nevertheless, several aspects of NOS are commonly cited in the literature, suggesting a similar pattern for defining the NOS. This section reviewed some of these aspects, i.e. the aspects we have also used to develop the instruments of data collection.

The seven aspects of NOS have been adapted from Das et al. (2019), who identified them as commonly used across contexts. Additionally, at least five of the seven aspects have been used in the context of student science teachers (Librea-Carden et al., 2021; Sumranwanich & Yuenyong, 2014; Vhurumuku, 2010) as well as in-service teachers in South Africa (Dekkers & Mnisi, 2003). First is the scientific method where there is an inclination to believe in the existence of a single and universal step-by-step scientific method that is used by scientists in carrying out scientific investigations (Leden & Hansson, 2019). However, there is no one single method for conducting scientific investigations. The second aspect of NOS is observation and inferences. Under this aspect, the emphasis is on understanding the distinction between observation and inferences. That is to say,

scientists can observe natural phenomena directly as well as by inferring (Lederman et al., 2013). Thirdly, student-teachers should be able to distinguish between scientific laws and theories, that is to say, understanding that while scientific laws describe the relationship among natural phenomena, scientific theories are statements explaining a natural phenomenon (Lederman et al., 2013). The fourth aspect of NOS is that of scientific knowledge being theory-laden. This aspect is concerned with the subjective nature of scientific knowledge. As individuals, scientists bring into scientific inquiry their expectations, prior knowledge and beliefs. As a result, scientists from different backgrounds might approach the same scientific phenomenon in different ways (Sumranwanich & Yuenyong, 2014). The tentative nature of scientific knowledge is another aspect of NOS which entails that scientific knowledge is subject to change as long as there is new and enough evidence to suggest so (Kite et al., 2021; Michel & Neumann, 2016). Nonetheless, treating science as absolute and unchanging has been a common misconception (Michel & Neuman, 2016). The sixth aspect of NOS is related to the socio-cultural influence on science. Under this aspect, science is viewed as a product of a particular culture. According to Lederman et al. (2013), factors such as religion, socio-economic influence, philosophy, societal values and politics affect the way science is accepted and conducted. Finally, there is the understanding that science is empirical but also a product of imagination and creativity. In this case, scientific knowledge comes not only from observation of natural phenomena and experiments, but also from human imagination, creativity and inferences (Lederman et al., 2013).

Learning Progressions: A Theoretical Framework

The study employs learning progressions (LPs) as a theoretical model for understanding student-teachers' NOS conceptions. Learning progressions are concerned with how students develop expertise in a specific domain over time. Thus, LPs encourage curriculum developers and teachers to set learning goals over an extended period of time and thus design instruction and assessment accordingly (Duschl, 2019). NOS as an essential learning domain in science education can also be learned at varying levels of complexity and depth over an extended period of time. For instance, Leden and Hansson (2019) proposed a NOS progression from elementary education (where NOS aspects are treated as simple and general) to teacher education (where NOS aspects are treated as interconnected and learners can address controversial issues). NOS progression has also been sought in terms of abstraction, where less abstract aspects of NOS such as tentativeness of science can be taught during the early years while abstract aspects such as socio-cultural embeddedness wait until later years (Leden & Hansson, 2019). Essentially, the success of NOS progression (in this case learners' informed conceptions of NOS) is influenced, among other things, by LP design features such as how well learning goals are designed, the mode and quality of instruction and the monitoring of the LPs over time (Duschl, 2019). Thus, in the present study the teacher education programme is treated as a segment of NOS progression.

Methods

Research Sample

We employed a comparative impact study where two post-intervention groups were compared, i.e. science student-teachers with experience in IBL and those with an additional NOS course. We assumed that the groups had similar understanding of NOS when joining the university. We also used non-science students as a baseline, a no-treatment group. The study involved 346 final-year student-teachers from one institution of higher learning in Tanzania. Final-year students were chosen so that their conceptions of NOS could maximally be attributed to the pre-service teacher education programme. The respondents were randomly selected from the three strata: science, science with an additional course on NOS and non-science-majoring student-teachers. Given the comparative nature of this study, these strata were selected so that comparisons in terms of the conceptions of NOS could be made between the three groups. A total of 640 questionnaires were physically

distributed to 300 and 340 targeted science and non-science majoring student-teachers, respectively. Questionnaires were completed individually in class during seminar sessions and students were given up to 25 minutes to complete a questionnaire. Participation in the study was voluntary. The participation rate for non-science majors was particularly low for reasons unknown to the researchers as only 106 students returned their questionnaire responses.

A total of 346 questionnaires were finally returned, resulting in a yield of 54.1%. The demographic characteristics of the sample are shown in Table 1.

The Instrument

This study used six sub-scales adapted from Das et al. (2019). In their study of Bhutanese students' conceptions of NOS, Das et al. (2019) adapted the Students Understanding of Science and Scientific Inquiry (Liang et al., 2008) questionnaire. The questionnaire consists of both open- and closed-ended items. This instrument was relevant because of its high internal reliability ($\alpha = 0.85$) for samples of cultural diversity. Additionally, the instrument was consistent with the theoretical framework used in the present study. The instrument consists of a wide range of items covering seven sub-scales of NOS, i.e. tentativeness; scientific theories and laws; the empirical nature of scientific knowledge; observation and inference; social and cultural embeddedness; the scientific method; and creativity and imagination. Only closed-ended questions were used in the present study. The purpose was to establish the extent and variations in NOS understanding among the respondents by groups. Our instrument was sent to two experts so as to check for its content validity. Given the differences in context, a pilot study was conducted with 30 student-teachers who filled the questionnaire and then were interviewed. Feedback from the experts and our pilot study resulted in slight modifications. For instance, only six sub-scales were retained. In this case, a sub-scale of 'scientific theories and laws' was omitted since it was perceived as confusing and it was overlapping with other sub-scales. It also yielded a comparatively low reliability score ($\alpha = 0.53$). Also, the sub-scale 'observation and inference' was renamed as theory-ladenness so as to maintain consistency with our theoretical framework. Finally, the modifications resulted in six sub-scales (see Table 2) used in the current study. Each sub-scale was measured using four items, resulting in a total of 24 Likert-type items. Consistent with Das et al. (2019), our instrument used a five-point scale (1 = Strongly Disagree to 5 = Strongly Agree), except that a central measure was renamed as 'neutral' from 'uncertain' as used in the original study. Renaming was done to reduce the central tendency error. The reliability scores for our instrument ranged from 0.69 to 0.82 in terms of Cronbach's α, as indicated in Table 2.

Data Analysis

Data analysis is organised according to the research questions. To establish whether or not student-teachers had informed conceptions of NOS, for each sub-scale the researchers coded the scale used in this study into three analytic levels. For each sub-scale, student-teachers with mean scores of less than three ($M < 3$) were considered as having naive conceptions of NOS, those with mean scores greater or equal to three but less than four ($M \geq 3 < 4$) were considered having limited conceptions of NOS while those having mean scores greater or equal to four ($M \geq 4$) were considered having

Table 1. Demographic characteristics of Sample (n = 346)

Characteristics	*N*	%
Sex		
Male	218	63
Female	128	37
Major		
Science	154	44.5
Science with additional NOS course	86	24.9
Non-science	106	30.6

Table 2. Examples of items and reliability analysis

Aspect of NOS	Number of items and reliability	Examples of items used
Scientific knowledge is theory-laden	4 (0.69)	Observations of the same phenomenon may yield different results because observations may be affected by scientists' prior knowledge and experiences
Scientific knowledge is tentative	4 (0.87)	Scientific knowledge can change any time given that new evidence is found
Science is not free from social and cultural influences	4 (0.71)	Scientific research can be biased because it is influenced by society and culture
Imagination and creativity	4 (0.76)	Scientific knowledge can be a product of imagination and creativity
Scientific method	4 (0.79)	Scientists use different types of methods to conduct scientific investigations
Science as empirical	4 (0.82)	Scientists use observations and measurements to obtain trustworthy evidence

informed conceptions of NOS. With regard to the difference between the groups, the researchers computed independent samples *t*-tests to establish whether or not any differences were statistically significant. Further, the measure of effect size was computed using Glass's delta, which is a recommended measure when the standard deviation and size between groups are different. During the early steps of data analysis, all items that were negatively worded (signifying misconceptions regarding NOS) were recoded (5 = 1, 4 = 2, 3 = 3, 2 = 4, 1 = 5) before any analysis was performed.

Ethical Considerations

For the purpose of protecting the respondents, the researchers obtained research clearance through the University of Dar es Salaam's research review board. Further, the participants had to fill in informed consent forms before they completed the questionnaires. The forms contained information regarding the participants' rights (e.g. rights to withdraw at any time) and the purpose of the study. Moreover, students were asked not to include their names so that their responses could not be traced back to individual respondents. Equally, their institution was anonymised.

Results

This study investigated student-teachers' conceptions of NOS by making a comparison among three groups. We present our findings according to our research questions.

Student Teachers' Conceptions of NOS

To respond to our first research question, we used mean score values to assign levels for each aspect of NOS. As mentioned earlier, student-teachers' conceptions of NOS were considered as naive, limited and informed if their mean score values were $M < 3$, $M \geq 3$ but < 4, and $M \geq 4$, respectively.

As shown in Table 3, across the groups, student-teachers had limited conceptions of NOS. However, exceptions were noted with regard to the aspects of *social and cultural influence on science* and *imagination and creativity* in which student-teachers (science majors and non-science majors) had naive conceptions of NOS. In other words, student-teachers believed that science is neither influenced by social and cultural values nor is it a product of imagination and creativity. On the contrary, student-teachers had informed conceptions of NOS on the aspect of the *empirical Nature of Science*.

Table 3. Conceptions of NOS

Sub-scale	Group	Mean	Level of NOS conceptions
Theory ladenness	Science majors	3.41	Limited
	Science majors with a special NOS course	3.55	Limited
	Non-science majors	3.42	Limited
Imagination and creativity	Science majors	2.98	Naive
	Science majors with a special NOS course	3.21	Limited
	Non-science majors	2.85	Naive
Scientific method	Science majors	3.90	Limited
	Science majors with a special NOS course	3.92	Limited
	Non-science majors	3.96	Limited
Science is empirical	Science majors	4.01	Informed
	Science majors with a special NOS course	4.20	Informed
	Non-science majors	4.00	Informed
Tentativeness nature	Science majors	3.66	Limited
	Science majors with a special NOS course	3.70	Limited
	Non-science majors	3.58	Limited
Socio-cultural influence	Science majors	2.95	Naive
	Science majors with a special NOS course	3.01	Limited
	Non-science majors	2.99	Naive

Comparing the Understanding of NOS of Science Student Teachers with Experience of IBL and Non-science Student Teachers

The second research question aimed at determining whether or not there are significant differences between the baseline group (non-science majors) and the intervention group 1 (science-majors with IBL experience) in terms of their conceptions of NOS. According to our results (Table 4), a significant difference among these groups was observed in one aspect of science as a *product of imagination and creativity*. Specifically, science majors with experience in IBL outperformed non-science majors on this aspect (Table 4). Although the effect size value was small, the difference was significant, implying that experiencing IBL resulted in positive gains in NOS conceptions of science being a *product of imagination and creativity*.

Table 4. t-Test results for science students trained in IBL and non-science students

Sub-scale	Group	Mean	*F*	Significance	Glass's delta
Theory ladenness	Science majors trained in IBL	3.41	0.073	0.102	0.000
	Non-science majors	3.42			
Imagination and creativity	Science majors trained in IBL	2.98	0.013	0.001*	0.427
	Non-science majors	2.85			
Scientific method	Science majors trained in IBL	3.90	2.660	0.653	0.063
	Non-science majors	3.96			
Science is empirical	Science majors trained in IBL	4.01	0.102	0.961	0.014
	Non-science majors	4.00			
Tentativeness nature	Science majors trained in IBL	3.66	0.126	0.120	0.024
	Non-science majors	3.58			
Sociocultural influence	Science majors trained in IBL	2.95	5.334	0.588	0.077
	Non-science majors	2.99			

*$p < 0.05$.

Comparing the Understanding of NOS of Science Student Teachers with Experience of IBL and Science Student Teachers with an Additional NOS Course

To assess the effectiveness of the additional NOS course, we compared NOS understanding of science student-teachers with experience of IBL (intervention group 1) and science student-teachers with an additional NOS course (intervention group 2). The results (Table 5) indicated only a significant difference in the aspect of *science as empirical*. In this case, student-teachers with an additional NOS course outperformed the other science students on the aforementioned aspect.

Discussion

This study investigated student-teachers' conceptions of NOS in one university in Tanzania. Generally, the findings indicated that student-teachers had limited conceptions of NOS on all the aspects but one (*science is empirical*), and that these limited conceptions of NOS hardly changed. On the one hand, our findings seem to replicate earlier studies—which found that student-teachers (Librea-Carden et al., 2021; Liang et al., 2008) and experienced teachers (Dekkers & Mnisi, 2003; Kite et al., 2021) tend to have limited conceptions of NOS. On the other hand, the findings imply serious flaws in the science teacher education programme and the NOS progression at large. First, the fact that student-teachers had limited conceptions of NOS implies that they joined the teacher education programme with limited understanding of NOS, signaling only a partial NOS progression from naive conceptions of NOS from primary to secondary school. Essentially, primary school students are capable of learning the aspects of NOS provided that the aspects are presented in simple and general form (Das et al., 2019). For instance, six graders were able to gain NOS understanding in the context of explicit NOS instruction (Khishfe & Abd-El-Khalick, 2002).

Secondly, we found that neither experiencing IBL nor taking an additional NOS course had a significant impact on student-teachers' overall understanding of NOS. Given that our sample comprised final-year student-teachers, these results have serious implication for the effectiveness of the science teacher education programme in enabling students to acquire informed conceptions of NOS. Moreover, the fact that we found no significant difference in NOS understanding between

Table 5. t-Test results for science students trained in IBL and those with additional NOS course

Sub-scale	Group	Mean	*F*	Significance	Glass's delta
Theory ladenness	Science majors trained in IBL	3.41	0.564	0.134	0.203
	Science majors with a special NOS course	3.55			
Imagination and creativity	Science majors trained in IBL	2.98	2.436	0.075	0.243
	Science majors with a special NOS course	3.21			
Scientific method	Science majors trained in IBL	3.90	0.019	0.857	0.028
	Science majors with a special NOS course	3.92			
Science is empirical	Science majors trained in IBL	4.01	4.072	0.018*	0.347
	Science majors with a special NOS course	4.20			
Tentativeness nature	Science majors trained in IBL	3.66	0.025	0.656	0.069
	Science majors with a special NOS course	3.70			
Sociocultural influence	Science majors trained in IBL	2.95	5.526	0.508	0.078
	Science majors with a special NOS course	3.01			

*$p < 0.05$.

science majors trained in IBL and non-science majors adds to that complexity. Meanwhile, according to Leden and Hansson (2019), student-teachers are expected to have well informed conceptions of NOS and also be able to understand NOS aspects as interconnected.

Despite the observed gaps in the science teacher education programme, two exceptions were noted. First, IBL experience resulted in gains in students' understanding of NOS on the aspect of science as a product of imagination and creativity. Such gains could probably be attributed to the inquiry process in the science teacher education IBL programme. However, this finding contradicts Bell et al. (2011), who found no significant impact of IBL activities on student-teachers' understanding of NOS aspects, including imagination and creativity. Generally, implicit approaches to NOS teaching have tended to be ineffective as compared with explicit ones (Bell et al., 2011; Duschl & Grandy, 2012; Khishfe & Abd-El-Khalick, 2002). Second, it is surprising that student-teachers' conceptions on the aspect of *science is empirical* were strengthened by the additional NOS course, even though the aspect was not an explicit focus of the course. This observation demands further exploration given that previous studies (e.g. Bell et al., 2016; Vhurumuku, 2010) indicate that explicit NOS instruction resulted in gains in student-teachers' NOS conceptions only in aspects that were also emphasised by the respective NOS courses.

We interpret our results by considering the NOS LP. In the context of developing NOS understanding, LPs entail how students can acquire informed conceptions of NOS in varying levels of complexity and depth over an extended period of time. Instructional design that ensures understanding of NOS is key in this respect. Meanwhile, three approaches to teaching NOS are popular. First, NOS aspects can be explicitly enacted as stand-alone topics, within the context of science processes (e.g. IBL, argumentation), within the context of a science content and within the context of socio-scientific issues (Bell et al., 2011). Indeed, explicit instruction, regardless of how it is enacted, has been found to enhance student-teachers' conceptions of NOS (Bell et al., 2011; Khishfe, 2021; Vhurumuku & Chikochi, 2017). The NOS course investigated in the present study explicitly emphasises three aspects, i.e. the tentative nature of scientific investigations, the scientific method and scientific theories and laws, as stand-alone topics. However, no significant gains were found in any of these aspects. This contradicts a study by Bell et al. (2011), who found that teaching NOS aspects as stand-alone topics resulted in significant gains in the aspects of tentative Nature of Science and scientific theories and laws. We argue that the ineffectiveness of the NOS course may be attributed to design features such as how well the goals were planned and implemented. Therefore, there is a need to investigate the design features of the course and review it to include other important NOS aspects such as cultural embeddedness, imagination and creativity in science and the empirical Nature of Science. Second, it has been claimed that, apart from experiencing an explicit curriculum, student-teachers can also develop informed conceptions of NOS implicitly by learning science through IBL (Das et al., 2019; Dekkers & Mnisi, 2003). In the context of Tanzania, analysis of curriculum documents suggests that largely the NOS progression follows the IBL path. However, it has been found that students rarely engage in IBL owing to factors such as large class sizes, teacher competences and inclinations to use IBL (Kinyota, 2020; Kafyulilo & Tilya, 2019). Thus, unless there are serious efforts to ensure that students engage in IBL, employing explicit instructional strategies to teaching NOS is recommended. Finally, NOS instruction can take a historic approach, where various NOS aspects are illustrated using episodes of the history of science.

Essentially, given the influence of the conceptions of NOS on how science is accepted and conducted, our findings sound an alarm to policy makers and curriculum developers in Tanzania. That is to say, the limited conceptions of NOS observed have serious implications for the way these future teachers will teach and conduct science. Indeed, teachers who themselves have limited conceptions of NOS are less likely to help students to gain an informed understanding of NOS (Kite et al., 2021; Nouri et al., 2021). Nonetheless, it is not too late to intervene. The findings call for a serious investigation of the NOS progression from the early years through teacher education. Thus, there is a need to research an appropriate NOS progression in the Tanzanian context, specifically, by identifying which NOS aspects should be taught and how they should be taught over time.

Limitations and Implications

While our study provides a snapshot of the status of the conceptions of NOS among student-teachers in a context where a paucity of research has been done on this subject, it is not without limitations. One major limitation of our study is that the participation rate of non-science-majoring student-teachers was low owing to poor return rates, something that might have compromised our results. Nonetheless, the sample size was enough to permit the analysis of data. Another limitation is that we only compared the three groups without performing pretest–posttest measurements. Nonetheless, the sample size is enough to provide a snapshot of the extent to which the science teacher education programmes enable students to develop NOS conceptions. Quasi-experimental designs are thus recommended in the future. Also, our design might have resulted in bias for students with an additional course on NOS since their volunteering to take the course could be due to their higher interest in NOS.

Conclusion and Recommendations

Generally, we find that student-teachers had limited conceptions of NOS after completing their education programme. This signifies the incapability of pre-service teacher programmes to enable science teachers acquire informed conceptions of NOS. Indeed, our findings suggest that student-teachers join pre-service programmes with limited conceptions of NOS. Also, our findings indicate that experiencing IBL does not automatically enhance student-teachers' understanding of NOS. Likewise, an additional NOS course had little impact on student-teachers' understanding of NOS. We recommend that proper and immediate intervention should commence, specifically to investigate the NOS progression and redesign it if necessary. Such investigation is necessary to inform the review of pre-service teacher education curricula. Meanwhile, we recommend a stand-alone NOS course that covers all six aspects of NOS under the current study.

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