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Learning Opportunities in Biology Teacher Education Contribute to Understanding of Nature of Science

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Abstract: In order to educate scientifically literate children, teachers are required to include nature of science (NOS) in their classroom practice. However, as biology teachers' own understanding of NOS is limited, promoting an initial understanding of NOS in teacher education is crucial. The aim of this study is to elucidate the importance of the first phase of teacher education for biology teachers' understanding of NOS. More precisely, the study aims to examine the relationship between institutional determinants (e.g., the type of teacher education programme) and learning opportunities for pre-service biology teachers' understanding of NOS. Pre-service biology teachers ($N = 232$) participated in a cross-sectional testing. The corresponding descriptions of $N = 649$ modules of biology teacher education from 20 German universities were analysed. Qualitative and quantitative methods were applied to relate the institutional determinants and the individual amount of learning opportunities to pre-service biology teachers' understanding of NOS. Results reveal that both institutional determinants as well as the amount of learning opportunities are related to pre-service biology teachers' understanding of NOS. This indicates that teacher education at university represents an important phase for biology teachers' understanding of NOS. The results are discussed in terms of consequences for further research and teacher education.

Keywords: nature of science; pre-service biology teachers; learning opportunities; institutional determinants

1. Introduction

Knowing about nature of science (NOS) and applying it to contextualised problems contributes to being scientifically literate [1–4]. Science literacy is documented as an educational goal of the Member States in the European Union, as well as the United States of America [5–7]. Scientifically literate citizens use knowledge from science, understand how knowledge is generated in science, and participate in socio-scientific decision-making [4]. Using knowledge and knowing how it is generated requires a corresponding understanding of nature of science (NOS). Therefore, to enable students to become scientifically literate citizens, the understanding of NOS has to be promoted in the science classroom. The teacher plays an important role in this regard, as teachers' NOS understanding is a necessary condition for NOS-teaching practices in the classroom [8]. In other words, in order to promote scientific literacy and to provide suitable instruction in their classrooms, teachers *themselves* need an appropriate understanding of NOS [9,10]. Nevertheless, science teachers' classroom practice reflects their understanding of NOS, which is typically not 'adequate' [8]. Studies on classroom practices for teaching NOS of in-service science teachers show that inadequate NOS understanding is related to less NOS teaching, e.g., [11]. Accordingly, teacher education should consider NOS to be of the same importance as knowledge of other science concepts [12] and prepare future teachers for

the demands of promoting the understanding of NOS in the classroom. The most formative phase for the professionalisation of teachers is the first phase of teacher education at university. The aim of this study is to elucidate the role of this phase for teachers' understanding of NOS. Since studies revealed that NOS differs depending on the discipline, e.g., [13], we refer to one specific scientific discipline: biology. More specifically, we focus on (1) institutional determinants and (2) NOS-related learning opportunities in biology teacher education programmes and their relation to pre-service biology teachers' understanding of NOS.

1.1. Understanding of NOS: Conceptualisation

Despite the continuing discourse between philosophers, historians, sociologists, and science educators concerning the aspects that constitute NOS, several aspects of NOS are identified [14–19] that reveal congruency between different authors. When comparing different NOS aspects, a clear analogy between the different conceptualisations of NOS in the literature becomes apparent [20,21]. Several aspects are addressed and defined or described similarly in each of the studies, which is interpreted as a consensus on relevant NOS aspects: therefore, a “*general aspects approach*” (GA; ([22], p. 452)) is considered for science education ([20]; discussion in the following paragraph). Speaking of ‘nature of science’ and not ‘the nature of science’ reflects the multiplicity of scientific research [23].

To summarise different NOS conceptualisations, for example, by McComas and Olson, Osborne and colleagues, as well as Lederman [14–19], we identified less controversial aspects which have been aligned in previous overviews (see Table S1 in the Supplementary Material; based on [20,21]): (1) tentativeness; (2) observations and inferences; (3) creativity and imagination; (4) subjectivity and objectivity; (5) social and cultural embeddedness; (6) diversity of scientific methods; and (7) scientific theories and laws. Two further aspects were added [20] as they represent epistemological beliefs [24]: (8) nature of knowledge and (9) nature of knowing. All nine NOS aspects have been the subject of discussion [20,21] and are characterised as follows: (1) Scientific knowledge is both *tentative* and *durable*; (2) scientific knowledge is based on *observations* (data) and *inferences* (evidence) and thus is empirical; (3) its generation requires *creativity* and *imagination*; (4) scientific knowledge comprises *subjectivity* as scientists form a community of practice with cooperation and collaboration; (5) furthermore, scientific knowledge is influenced by *social* and *cultural contexts*; (6) *scientific methods* represent the methodologically diverse basis of working scientifically (including experimentation, literature reviews, observation, simulation); (7) *laws* and *theories* are distinct but yet related; (8) the *nature of knowledge* is characterised by its certainty and simplicity; (9) the *nature of knowing* comprises the sources and justification of knowledge. Furthermore, those less controversial aspects are reflected in instruments for the survey of NOS understanding like qualitative approaches, for example, *Views of Nature of Science Questionnaire* (VNOS; [25]), and quantitative Likert-style questionnaires, for example, the questionnaire *Student Understanding of Science and Scientific Inquiry* (SUSI; [26]; see Section 2.3.1), which is based on NOS aspects from VNOS by Lederman and colleagues [25,27].

However, bundling all aspects identified in different studies into the GA conceptualisation of NOS is problematic for several reasons [21,22]: a short list abbreviates the diverse nature of science; it hides discipline specific differences that are not common across all science domains [28–30]; GA aspects are not limited to scientific knowledge [28]; and process of science (inquiry) is decoupled from its product [1]. Even though Kampourakis agrees with the criticism, he [21] argues for the benefits of GA conceptualisation as (1) being a didactic transposition; (2) addressing pre-conceptions (not demarcating science from non-science); (3) being a starting point for further elaboration of discipline-specific differences; and (4) complementing “*general aspects*” and “*family resemblance*” approaches with each other (p. 676).

The diverse nature of science aspects is embedded throughout the courses in science teacher education. A careful analysis of learning opportunities in science teacher education therefore has to account for all courses and not only for those explicitly mentioning the promotion of nature of

science. Since the diverse aspects of nature of science depend on the scientific content in which they are embedded, they cannot solely be taught as a general list of features in just one context [31].

1.2. Teachers' Understanding of NOS and the Role of Teacher Education

Teachers' own understanding of NOS is crucial for providing adequate classroom instruction [8]. Conceptually, it is very closely related to teachers' professional knowledge [16,31,32]. Professional knowledge represents the necessary knowledge base for effective teaching and is described as consisting of three domains: (1) content knowledge (CK); (2) pedagogical content knowledge (PCK); and (3) pedagogical knowledge [33]. In particular, the content-related domains [i.e., CK and PCK] are important for teachers' understanding of NOS. CK represents the knowledge of the principles and concepts of a certain domain (here biology) [33]. PCK is described as a necessary knowledge domain to make the subject matter comprehensible for students [33]. Several facets of PCK are described, but there is consensus concerning two facets of PCK: (1) knowledge of instructional strategies for teaching and (2) knowledge of students' understanding [33–36]. CK is strongly intertwined with teachers' own understanding of NOS, whereas PCK is associated with teaching NOS [31,32].

As mentioned above, science teachers often lack an adequate understanding of NOS [16]. Capps and Crawford [11] found that less understanding of NOS leads to less NOS teaching. Their study [11] demonstrates that in-service teachers believed their teaching practice to include NOS and inquiry even when it did not. This is explained by the in-service teachers' limited views of NOS and inquiry. Similarly, Bartos and Lederman [37] found a disjunction of in-service teachers' knowledge structures for NOS as well as scientific inquiry and those of their teaching practice. For in-service teachers who participated in a two to five years intensive science education programme on NOS instruction, Herman, Clough, and Olson [38] provided evidence for the additional effort that is needed beyond regular science courses to promote NOS understanding. Still, there exists no automatic translation of teachers' understanding of NOS and their classroom practice. Therefore, its development and relating factors are concerns of further research ([8], p. 614). Different scholars engaged in the investigation of the development of teachers' understanding of NOS and the role of learning opportunities. They present evidence for both in-service as well as pre-service teacher education. The findings are mixed.

Institutional determinants (such as the type of teacher education programme) are not described as predictive for teachers' understanding of NOS [8]. Nevertheless, it is known from studies related to the professional knowledge of teachers that institutional determinants are indeed predictive, e.g., [39–41]. In a sample of American pre-service science teachers (graduated), no relation between the number of biology courses and knowledge of NOS was observed [42]. Besides an inadequate understanding of NOS, a sample of Turkish pre-service teachers even showed a regression of NOS understanding, with Master degree students holding more naive views than Bachelor degree students [43]. More coursework during science education programmes or courses on practicing science does not consistently improve NOS understanding, hence explicit-reflective interventions seem promising. That is where intervention studies investigate the effects of two different approaches, an implicit and an explicit-reflective approach, e.g., [44]. However, even for intervention studies, the findings are mixed. Golabek and Amrane-Cooper [45] present findings on an intervention with 75 pre-service teachers that indicate inconsistent improvement in NOS understanding. They concluded that the intervention was too implicit and the development of nature of science views is possibly a long-term process. Inconsistent changes in NOS understanding of pre-service science teachers is related to several factors. After a one-semester university course focusing on inquiry and NOS, most undergraduate pre-service science teachers improved their NOS understanding, but not consistently over all NOS aspects [46]. NOS aspects like theory/law, tentativeness, and socio/cultural were less likely to change. Furthermore, instructional (explicit-reflective), motivational (personal and social), and socio-cultural factors influenced the development of NOS understanding. Based on their finding of a small effect ($\eta^2 = 0.04$; not yet statistically significant) of semester on NOS understanding of German science teacher students, Krell and colleagues [47] investigated the effects of a new STEM curriculum. The authors

built on their inference that the regular curriculum of content knowledge and practicing science does not affect NOS understanding and therefore showed that combining two versions of explicitly teaching NOS [44] is effective.

The presented studies show, in accordance with previous research, that explicit-reflective approaches promote NOS understanding and add that inconsistencies depend on: (1) institutional (learning opportunities, teaching approaches, duration); (2) individual (motivation, socio-cultural); and (3) construct (different difficulty of specific aspects, discipline-specific) factors. Learning to teach nature of science and science inquiry requires explicit professional development starting with authentic inquiry experiences [48] and continuing learning opportunities to learn and to teach NOS [10]. This is reflected by the two versions for teaching NOS [44]: teaching a consensus list or engaging learners with scientific practices [13,44]. How both versions complement each other has already been discussed [21]. In order to know how science teacher education integrates the standard documents [5,7], additional research is needed [9]. Almost all of the aforementioned studies investigated how interventions of NOS instruction are put into practice. However, it has to be considered whether and how NOS is taught in science teacher education at a university level. To the best of our knowledge, none of the prior studies analysed regular biology teacher education programmes to investigate their relationship to the promotion of pre-service biology teachers' understanding of NOS. Moreover, the meaning of institutional determinants remains unclear although research on teachers' professional knowledge indicates relevance (e.g., of the type of teacher education programme; [39–41]).

1.3. Aim of the Study and Research Questions

The first phase of teacher education represents an important period for the professionalisation of teachers, e.g., [49]. Fostering the understanding during this phase supports prospective teachers to provide effective instruction in the science classroom. Nevertheless, there is no consensus about the effectiveness of teacher education at university for the development of NOS understanding (this concerns both the institutional determinants as well as learning opportunities). The study at hand aims to elucidate the role that teacher education plays for pre-service biology teachers' understanding of NOS at university. To gain information about the role of teacher education for the understanding of NOS, we focus on learning opportunities over the course of teacher education at university (besides explicit intervention studies like in all papers listed before), as well as on institutional determinants (e.g., the type of teacher education programme, cf. [39,41]). The following research questions guided our study:

Learning opportunities

1. How are NOS learning opportunities distributed in different degree programmes (Bachelor and Master) of teacher education at university?
2. How are NOS learning opportunities (number and ECTS credit points) related to pre-service teachers' understanding of NOS (NOS score)?

Institutional determinants:

3. How are (1) the semester; (2) the type of teacher education programme (academic vs. non-academic track); and (3) the study of a second school subject (science vs. other subjects) related to pre-service biology teachers' NOS?

2. Materials and Methods

2.1. Research Design

The study at hand is embedded in the KeiLa-project (*Kompetenzentwicklung in mathematischen and naturwissenschaftlichen Lehramtsstudiengängen*; The Development of Professional Competence in pre-Service Mathematics and Science Teacher Education). A total of 25 German universities participated

in the project. The aim of KeiLa is to examine the development of biology, physics, chemistry, and mathematics pre-service teachers' professional competence in the first phase of teacher education at university. The focus lies in particular on the identification of individual and institutional determinants for the development of teachers' professional competence. The study started in 2014 and includes four main measuring points (assessment of professional competence with paper and pencil tests at the universities; test time 4 h; autumn of 2014–2017) and three interim inquiries (online assessment of learning opportunities; test time 30 min; summer of 2015–2017).

All participating pre-service teachers gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki. No approval by the Ethics Committee of Kiel University was necessary. This is because the testing was carried out anonymously and proceeded in the familiar surroundings of university lecture halls and home, therefore causing no distress to the participating teacher students.

2.2. Sample

The study at hand refers to the data of pre-service biology teachers' from 20 German universities which were collected during the second main measuring point. In total, 232 pre-service biology teachers (78% female) participated. On average, the participating pre-service teachers were 22.11 years old and in the first (26%), third (35%), fifth (14%), or seventh (24%) semester. In the German school system in particular two types of tracks are distinguished. On the one hand, academic track schools certify their students for further education at universities. Whereas, on the other hand, within the non-academic track, students are prepared for further vocational education. According to this distinction, pre-service teachers can choose between two teacher education programmes. One that certifies them for a career in academic track schools and another one that certifies them for a career in non-academic track schools. In total, 43.1% participated in a teacher education programme for future academic track teachers. Additionally, 31% of the participating pre-service teachers study a second science subject (physics or chemistry).

2.3. Instruments

2.3.1. Understanding of NOS

To measure pre-service biology teachers' understanding of NOS, we applied a paper and pencil test ($M = 80.94$, $SD = 9.20$) including 23 items (e.g., "Scientists observations of the same event will be the same because scientists are objective" [26]). The instrument consists of Likert-type items with possible answers from 'strongly disagree' to 'strongly agree'. The scale shows a good reliability ($\alpha = 0.76$) and the difficulty of items ranges between 0.33 and 0.88 and discrimination indices between 0.13 and 0.48. As mentioned above, both quantitative and qualitative instruments referring to less controversial NOS aspects are available for surveying NOS understanding (see Section 1.1). We decided to apply the Likert-style instrument developed and established by Liang and colleagues [26], which was previously used in a German sample of pre-service science teachers [47]. This study is embedded in the KeiLa-project. This project focuses on several aspects of teachers' professional competence, such as professional knowledge or motivational orientations. To not exceed an appropriate amount of test time (4 h of test time is still long), time-efficient instruments were chosen.

2.3.2. Content Knowledge

In addition to the understanding of NOS, we measured pre-service biology teachers' CK ($M = 28.38$, $SD = 7.98$). Using this instrument allows us to ensure the construct validity of the NOS-instrument. The understanding of NOS and CK are conceptually closely related (e.g., concerning knowledge about the application of scientific methods). Moreover, CK plays an important role for teachers' own understanding of NOS [16,31,32]. Accordingly, it is important to ensure the separability of the constructs to measure the understanding of NOS accurately.

The instrument was developed and validated in the KiL-project (*Messung professioneller Kompetenzen in mathematischen und naturwissenschaftlichen Lehramtsstudiengängen*; Measuring the professional knowledge of preservice mathematics and science teachers; [50,51]). It covers five content areas: (1) ecology; (2) genetics; (3) evolution; (4) morphology; and (5) physiology. In total, 37 closed-ended items were applied to measure pre-service biology teachers' CK (e.g., "Metazoa are the taxon of multi-cellular animals. The leaves of plants which live in arid regions display characteristic features. Check three common features of these plants' leaves: low leaf to surface ratio; dark green colour; sunken stomata; waxy cuticle; long-pointed leaf tips; vertical arrangement of leaves."). The scale shows a good reliability ($\alpha = 0.82$). The difficulty of items ranges between 0.07 and 0.76 and discrimination indices between 0.08 and 0.38.

2.3.3. Institutional Determinants

To gain information about the institutional determinants for the development of the understanding of NOS, the participants were asked to provide information about their semester (number of semester), their second school subject (second science subject [physics or chemistry] vs. second subject which is not a science subject), and their type of teacher education programme (teacher education programme for prospective academic track teachers vs. teacher education programme for prospective non-academic-track teachers).

2.4. Data Analysis

In order to answer the research questions, two different research paradigms were used. We applied (1) qualitative content analysis [52] for the identification of learning opportunities and (2) a quantitative approach [regression analysis] for investigating the relationship between institutional determinants as well as learning opportunities and learning outcomes for nature of science. To ensure the construct validity of the NOS-instrument, we applied a validity check prior to the actual analyses.

2.4.1. Validity Check

The aim of the validity check is to ensure the empirical separability of pre-service biology teachers' (1) understanding of NOS and (2) CK. In order to check the empirical separability, we applied Rasch analysis in ACER Conquest [53]. The item response theory provides the mathematical model for the Rasch analysis [54]. A Rasch model predicts the probability for a certain participant to solve a certain item correctly by considering the person's ability as well as the item's difficulty [55]. Furthermore, it allows researchers to compare models with different numbers of dimensions concerning their model fit.

We specified and compared two models. Different indices give information about the fit of the respective model. The final deviance considers the likelihood that the observed data and the assumed model fit [56]. The lower the deviance, the higher the fit. Information-based criteria such as AIC (Akaike's information criterion; [57]) and BIC (Baye's information criterion; [58]) provide further information about the fit. Again, lower coefficients indicate a better fit. Model 1 assumes an integrated construct which covers both understanding of NOS and CK. Within this model, these two constructs are not unique but merely facets of one construct. The second model assumes two unique domains: (1) understanding of NOS and (2) CK. The results reveal that the two-dimensional model significantly outperforms the one-dimensional model ($\chi^2 [2] = 217.96, p < 0.001$), indicating that the understanding of CK and NOS represents two empirically separable and thus unique constructs. Although the constructs are empirically separable, they are positively correlated ($r = 0.34, p < 0.001$). The results support the construct validity of the NOS-instrument. Table 1 gives further information about the fit of the two models.

Table 1. Final deviance and information-based criteria for two models considering the understanding of NOS and CK.

	Component	Model 1	Model 2
Allocation to dimension	Understanding of NOS CK	A A	A B
Deviance		27,514.86024	27,296.90412
AIC		27,820.8602	27,606.9041
BIC		28,348.2111	28,141.1484

Note: A = indicator(s) of dimension 1; B = indicator(s) of dimension 2.

2.4.2. Qualitative Content Analysis

The aim of the qualitative content analysis was to identify learning opportunities for pre-service teachers' understanding of NOS. Three levels of learning opportunities can be distinguished which comprise (1) the intended; (2) the enacted; and (3) the lived object of learning [59]. The identification of learning opportunities from two different degree programmes (Bachelor and Master) and 20 different universities requires the analysis of the science teacher education programmes. Detailed observations of actual university courses (enacted and lived object of learning) would cost an economically unjustifiable amount of time and effort. Accordingly, we refer to the first level of learning opportunities (the intended object of learning). However, the programmes of science teacher education are legitimised in an accreditation process which is based on module manuals [60]. Therefore, the module manuals provide an approximation of learning opportunities by the number of mentioned NOS aspects (number) and the number of ECTS (European Credit Transfer System) credit points given for the module (credit points). To identify learning opportunities through qualitative content analysis (QCA), (1) the text corpus and the units for analysis are defined; (2) categories for analysis, their definition, and examples are provided; and (3) interrater reliability (Krippendorff's α) for the identification of learning opportunities is calculated (basic ideas of QCA: [52]).

- (1) A corpus of text documents (called module manuals) from 20 universities' biology teacher education programmes forms the basis for the identification of learning opportunities. For strands of teacher education (e.g., secondary level), module manuals define the respective modules that pre-service teachers have to take. The minimum requirements of a module description include: content and qualification goals of a module, teaching methods, requirements for awarding credit points, credit points and grades, frequency of methods offered, workload, and duration of modules. $N = 649$ modules were analysed. We paid attention to considering the module manuals valid at the point in time when teacher students participated in the survey.
- (2) A priori specified categories for QCA were deduced from literature on NOS aspects [20,21] and aligned with the instrument for measuring the understanding of NOS [26]. Table S2 in the Supplementary Material gives an overview of the categories we used, their definition, and typical examples from the analysis of module manuals.
- (3) Reliability of category application is assured by discussing and revising the categories after piloting them. Furthermore, the reliability of category application is quantified by different raters in a coefficient of agreement, Krippendorff's α . In total, 25% randomly chosen modules of the total number of modules ($n = 163$) were coded by two trained raters. Coding the frequency of learning opportunities revealed a substantial agreement ($\alpha = 0.75$) and coding the credit points for learning opportunities revealed a perfect agreement ($\alpha = 1$; interpretation according to [61]).

2.4.3. Quantitative Approach—Regression Analyses

To investigate (1) the relationship between the understanding of NOS and institutional determinants (number of semester, second school subject, type of teacher education programme), as well as (2) the relationship between the understanding of NOS and the frequency of learning

opportunities, we applied linear regression analyses using the software SPSS (version 23.0) (IBM Corp., Armonk, NY, USA).

At first, we examined the relationship between pre-service biology teachers' understanding of NOS and institutional determinants. The dependent variable is the participants' understanding of NOS. We decided to use the weighted maximum likelihood method (WLE; [62]) to estimate the participants' NOS-scores in Acer Conquest [53]. WLE scores take the item difficulty into consideration to estimate the ability of the participant [63] and are thus less biased compared to true scores as sum scores or mean scores. The independent variables consist of the number of semester, the second school subject (0 = the second school subject is not a science subject, 1 = the second school subject is chemistry or physics), and the type of teacher education programme (0 = teacher education programme for prospective non-academic track teachers, 1 = teacher education programme for prospective academic track teachers). We specified four regression models. Model 1 to Model 3 consider the independent variables in separate regression analyses, whereas Model 4 considers all three independent variables.

Subsequently, we analysed the relationship between pre-service biology teachers' understanding of NOS and learning opportunities. Learning opportunities were identified using a qualitative content analysis (see Section 2.4.2). The results of this analysis allowed us to determine an individual amount of NOS learning opportunities for every participant. The understanding of NOS serves as the dependent variable, whereas the frequency of the identified learning opportunities represents the independent variable. Furthermore, we added the second school subject (0 = the second school subject is not a science subject, 1 = the second school subject is chemistry or physics), as well as the type of teacher education programme (0 = teacher education programme for prospective non-academic track teachers, 1 = teacher education programme for prospective academic track teachers) as control variables. Because of the high correlation between the frequency of learning opportunities and the number of semesters ($r = 0.71, p < 0.001$), we decided not to consider the number of semesters as a control variable in the model to avoid collinearity.

Again, different regression models were specified. The first model only considers the dependent and the independent variable. In the second model, the control variables are added, in addition to the dependent and independent variable.

3. Results

In a first step, we identified learning opportunities in the teacher education programmes of the participating universities. Accordingly, we first present the distribution of learning opportunities over two degree programmes (Bachelor and Master). Subsequently, we present the findings concerning the relationship between pre-service biology teachers' understanding of NOS and institutional determinants, as well as the frequency of learning opportunities.

3.1. Distribution of NOS Learning Opportunities in Science Teacher Education Programmes

The comparison between the degree programmes in Table 2 reveals that the Bachelor programme offers more learning opportunities than the Master programme. Even when accounting for the length of the degree programmes (Master: four semesters and Bachelor: six semesters), the differences remain clear. Further, there are differences between the two stages of the Bachelor's programme: In the first stage, there are more than twice as many learning opportunities. Therefore, it can be noted that the number of NOS learning opportunities decreases during the Bachelor degree programme and also from the Bachelor to the Master degree programme.

Table 2. Number of NOS learning opportunities presented as the median (*Mdn*) and range (*Min.*; *Max.*) depending on the degree programme of *N* = 20 universities.

Degree Programme	Learning Opportunities		
	total	<i>Mdn</i>	<i>Min.</i> ; <i>Max.</i>
Bachelor	386	14.0	0; 74
1.–3. semester	242	7.5	0; 55
4.–6. semester	144	6.5	0; 24
Master	132	6.0	0; 23

Note: Missing learning opportunities to the total number of *N* = 1230 are included in optional modules without assignment to specific semesters.

Furthermore, irregularities during the QCA were accounted for as the frequency of learning opportunities that differed between the NOS categories. The distribution of the learning opportunities from the module manuals for each NOS aspect is summarised in Table 3. The comparison between different NOS aspects reveals that most of the learning opportunities concern scientific methods (~70%). However, relating theory and law has never been mentioned in any learning opportunity (0%), whereas the tentativeness and durability of theories was mentioned at least eight times (~1%). The second most frequent aspect represented learning opportunities for knowledge generation (~17%).

Table 3. Number of NOS aspects and percentage share (%) of all learning opportunities (*N* = 1230).

NOS Aspect	Learning Opportunities	
	Total	%
(1) scientific methods	860	69.92
(2) tentativeness	8	0.65
(3) observations and inferences	23	1.87
(4) scientific theories and laws	0	0
(5) subjectivity and objectivity	1	0.08
(6) social and cultural embeddedness	77	6.26
(7) creativity and imagination	8	0.65
(8) nature of knowledge	48	3.90
(9) nature of knowing	205	16.67

3.2. Institutional Determinants of Preservice Biology Teachers' Understanding of NOS

To determine the relationship between the understanding of NOS and the considered institutional determinants (number of semester, second school subject, type of teacher education programme), we specified different regression models (see Section 2.4.3). The results of Model 1 reveal a significant positive relationship between pre-service biology teachers' understanding of NOS and the number of semesters, indicating that the understanding of NOS increases over the course of teacher education at university. Model 2 shows a significant positive relationship between pre-service biology teachers' understanding of NOS and the second science subject. Pre-service biology teachers specialising in two science subjects remarkably outperform participants without a second science subject. The results of Model 3 indicate a significant positive relationship between pre-service biology teachers' understanding of NOS and the type of teacher education programme. This result suggests that pre-service biology teachers who participate in a teacher education programme that certifies graduates for a career in an academic track school score significantly higher concerning the understanding of NOS compared to the pre-service biology teachers who participate in a teacher education programme that certifies graduates for a career in non-academic track schools. Model 4 considers all independent variables in one model. The results still reveal a positive relationship between the institutional determinants and pre-service biology teachers' understanding of NOS. See Table 4 for detailed results.

Table 4. Results of the regression analyses (standard errors in parenthesis; standardized regression coefficients).

Parameter	Model 1	Model 2	Model 3	Model 4
Semester	0.19 ** (0.02)			0.18 ** (0.02)
Second science subject		0.19 ** (0.07)		0.17 * (0.08)
Type of teacher education programme			0.19 ** (0.08)	0.13 * (0.07)
R ²	0.04	0.03	0.04	0.09

Note: Second science subject: (0 = the second school subject is not a science subject, 1 = the second school subject is chemistry or physics); Type of teacher education programme: (0 = teacher education programme for prospective non-academic track teachers, 1 = teacher education programme for prospective academic track teachers).

3.3. Learning Opportunities' Relation to Understanding of NOS

We quantified the identified learning opportunities for pre-service teachers' understanding of NOS to examine the relationship between pre-service biology teachers' understanding of NOS and these learning opportunities. Different regression models were specified. Model 1 considers pre-service biology teachers' understanding of NOS and the frequency of learning opportunities. The results reveal a significant positive relationship between these two variables, indicating that the uptake of learning opportunities leads to an increase of pre-service biology teachers' understanding of NOS. Model 2 considers additional control variables (second school subject, type of teacher education programme). The positive relationship between pre-service biology teachers' understanding of NOS and the frequency of learning opportunities remains. See Table 5 for detailed results.

Table 5. Results of the regression analyses (standard errors in parenthesis; standardised regression coefficients).

Parameter	Model 1	Model 2
Frequency of learning opportunities	0.17 * (0.004)	0.14 * (0.004)
Second science subject		0.15 * (0.08)
Type of teacher education programme		0.13 * (0.07)
R ²	0.03	0.08

Note: Second science subject: (0 = the second school subject is not a science subject, 1 = the second school subject is chemistry or physics); Type of teacher education programme: (0 = teacher education programme for prospective non-academic track teachers, 1 = teacher education programme for prospective academic track teachers).

4. Discussion

Teachers' own understanding of NOS is important for providing effective NOS-related instruction in the classroom [8]. Unfortunately, teachers' understanding of NOS is mostly inadequate [16]. The first phase of teacher education is described as crucial for teachers' professionalisation [49] and thus also for the development of teachers' understanding of NOS. Elucidating the effects of this phase of biology teacher education—i.e., institutional determinants and learning opportunities—on the understanding of NOS of pre-service biology teachers is the aim of the reported study.

We will discuss our results in detail in the following. Moreover we disclose possible limitations of the study and present implications for further research, as well as for teacher education.

4.1. Distribution and Characterisation of Learning Opportunities in Biology Teacher Education

Learning opportunities for NOS are more prevalent at the beginning of science teacher education programmes: the number of NOS learning opportunities in the first half of the Bachelor's programme (1.–3. Semester) exceeds the number of learning opportunities in the second half (4.–6. Semester) by twice as much, which skews the distribution in favour of the beginning of the Bachelor programme. The distribution of NOS learning opportunities is partly explained by the NOS aspects addressed in the learning opportunities. This observation already explained why NOS understanding decreases during

the academic career, with PhD students holding the most naive views [43]. Especially the first courses in science teacher education programmes are focused on practicing science methods in the laboratory without explicit reflection [64]. However, combining both approaches [65] of practicing science and reflecting science [44] requires that later stages of biology teacher education programmes offer further reflective learning opportunities. Especially, science education courses in the Master programme where scientific reasoning and NOS is explicitly taught fulfil this explicit-reflective approach [64]. Through our analysis of data on learning opportunities from 20 German universities, a quantitatively smaller number of explicit-reflective approaches were observed in graduate programmes.

Learning opportunities are mostly focused on scientific methods and least on the relation of theories and laws. NOS aspects addressed in the learning opportunities reflect some of the observations made on learning outcomes for different NOS aspects, i.e., some NOS aspects are more difficult to understand, e.g., [8,46]. For example, the relation of theory and law was found to be difficult to understand by pre-service science teacher students, e.g., [26,32,47]. We suggest that this is reflected in our observation of zero representation of a theory-law-differentiation in module manuals (but see [65]). Even in German school science textbooks, the relationship between theory and law is hardly discussed [66]. Therefore, the authors demand that at least in the teacher training, a stronger integration of NOS must be focused in order to use these textbooks accordingly [66]. On the other hand, while most learning opportunities concern scientific methods (~70%; see Table 3), the findings of some studies point to difficulties concerning students' understanding of scientific methods [45,47]. To what extent scientific practices are effective for promoting NOS understanding is the subject of discussions. The idea of two approaches for learning explicitly about NOS considers one domain-general approach based on consensus heuristics and one contingent approach which links discipline-specific practices with the discussion of NOS aspects [44]. The second approach assumes that working scientifically ("doing science") also has an effect on learning about science ([67], p. 2584). However, distinguishing both doing science and learning about science admits that the latter requires further explicit teaching strategies [67]. Therefore, taking both approaches into consideration promises to be more effective [47]. However, learning opportunities for scientific methods are more prevalent in the analysed modules.

Concerning written representations of NOS in German school science textbooks, Marniok and Reiners [66] assume an author effect—no reaction followed the published results (cf. [23])—and suggest approaching authors directly. In the study at hand, representing NOS-related learning opportunities in module manuals, we look forward to a greater response, which will stimulate discussion and further development of the module manuals.

4.2. The Meaning of Institutional Determinants and Learning Opportunities for Pre-Service Biology Teachers' Understanding of NOS

The results reveal a positive relationship between the assumed institutional determinants (semester, second school subject, type of teacher education programme) and pre-service biology teachers' understanding of NOS. The results indicate that teacher education at university plays an important role in the development of pre-service biology teachers' understanding of NOS. The results are contrary to the conclusions of Lederman and Lederman [8], which described that academic background variables are not predictive for understanding of NOS. We will discuss the meaning of these variables in more detail.

Specifically, we found that pre-service biology teachers' understanding of NOS increases during the course of teacher education. This contrasts to the finding of Dogan and Abd-El-Khalick [43], who found that understanding of NOS decreases during the academic career. Nevertheless, as the number of semesters serves as a proxy for several learning opportunities (not only related to NOS), the positive relationship seems plausible. What is interesting is that the understanding of NOS increases, although we know from our qualitative content analysis that the amount of learning opportunities stagnates in the later stage of teacher education. This result could be explained by the finding that learning

opportunities at the later stage of teacher education are more often related to reflection [64], which is especially beneficial for the formation of teachers' understanding of NOS, e.g., [8,47].

Beyond the number of semesters, we found the second school subject (science vs. non-science) as well as the type of teacher education programme (academic track vs. non-academic track) to be predictive for pre-service teachers' understanding of NOS. Pre-service teachers with a second science subject outperform pre-service teachers with another second subject. We assume that pre-service teachers with a second science subject have more NOS-related learning opportunities as NOS also plays an important role in the other science disciplines [13]. Accordingly, a positive relationship seems plausible. Participants of an academic track teacher education programme score higher concerning the understanding of NOS. We know from other studies that the type of teacher education programme impacts on teachers' CK, e.g., [40]. Pre-service teachers attending a teacher education programme which certifies them for a career at academic track schools participate in more CK-related university courses and have more learning opportunities in this regard. We assume that the higher amount of CK-related learning opportunities also impacts on pre-service teachers' understanding of NOS, as CK and NOS are very closely related [31,32].

To gain a deeper insight into the meaning of learning opportunities, we referred to the findings of the qualitative content analysis and examined the relationship between pre-service biology teachers' understanding of NOS and the frequency of learning opportunities. As expected, we found that pre-service biology teachers' understanding of NOS increases with the amount of learning opportunities. This result further supports the assumption that teacher education at university represents a crucial phase for the formation of pre-service biology teachers' understanding of NOS.

What is important to mention is the relatively small amount of variance that is explained by institutional determinants and the frequency of learning opportunities. One explanation is that pre-service teachers may be allowed to choose between courses. Institutional determinants such as the structure of the study programme only have small effects [68]. In a comprehensive analysis, up to 80% of variance in learning opportunities was explained by individual teacher students' characteristics [69]. Furthermore, in accordance with the observation that individual factors influence the uptake of learning opportunities [69], the development of NOS understanding is also determined by motivational and socio-cultural factors [46]. We further assume that the limited explanation of variance is caused by the level of learning opportunities we considered for the analysis. As mentioned above, we focused on the intended learning, i.e., on learning opportunities we identified within the curricula of the participating universities. Characteristics of lesson quality (e.g., cognitive activation; [39]) could serve as variables to further explain the relevance of NOS-related learning opportunities for the understanding of NOS. Beyond the limited information about the quality of the considered learning opportunities, we also have no information about the pre-service teachers' uptake of learning opportunities, which is a further important aspect for the success of learning opportunities [70].

4.3. Strengths and Limitations

The study at hand refers to the data of 20 German universities from different federal states in Germany. Moreover, we considered both institutional determinants and learning opportunities. This allows us to draw a detailed picture of the consideration of understanding of NOS in teacher education. However, one issue is related to the cross-sectional design of the study. Our results reveal first hints concerning the development of pre-service biology teachers' NOS, but further longitudinal observations could help to understand this progress in more detail. As the KeiLa-project provides longitudinal data, we will further investigate the formation of pre-service biology teachers' understanding of NOS.

We thoroughly analysed the module manuals of the participating universities concerning learning opportunities for the understanding of NOS. Therefore, our research approach is strong in identifying NOS-related learning opportunities on the level of concepts that are planned to be taught in biology teacher education (intended objects of learning; [59]). Moreover, we were able to assign an individual

amount of learning opportunities to every participant. Nevertheless, we had no insight into the quality of the teaching strategy based on the respective learning opportunities (enacted object of learning; [59]) or the perception and uptake of learning opportunities by the teacher students (lived object of learning; [59]). This is possibly reflected in the relatively small amount of variance that the learning opportunities explain in pre-service biology teachers' understanding of NOS. Both the consideration of the quality of the respective learning opportunities and the uptake of the learning opportunities by the pre-service teachers could help to further understand the meaning of learning opportunities for the formation of pre-service biology teachers' understanding of NOS.

4.4. Implications

Our results reveal that teacher education at university plays an important role in the formation of pre-service teachers' understanding of NOS. The existing learning opportunities—mainly on scientific methods—are related to a positive development of NOS understanding. However, learning opportunities for other NOS aspects are scarce and not covered by all university curricula. To understand this relationship in more detail, further research is needed.

First, it would be fruitful to model the development of the understanding of NOS, as well as the actual use of NOS-related learning opportunities, in a longitudinal approach. This will contribute further information supporting the relevance of learning opportunities. Moreover, it will help to identify relevant topics to foster the understanding of NOS. Beyond that, a longitudinal approach could further explain the meaning of content-related professional knowledge for the formation of the understanding of NOS (e.g., the contribution of CK to the development of NOS; [31]).

Second, as mentioned above, more insight into the quality as well as the uptake of learning opportunities is necessary. To learn more about the quality, observation of university courses is required. However, observations of hundreds of courses would be a very expensive approach. To gain an insight into the uptake of learning opportunities, an alternative could be to ask the pre-service teachers to rate the quality of the learning opportunities, as well as how many hours of preparation and follow up-work they conduct.

Third, while our results from the analysis of learning opportunities in module handbooks were suitable to be related to the development of NOS understanding, a deeper analysis would reveal detailed information on the status quo in German science teacher education. Therefore, we recommend analysing which NOS aspects are addressed during specific semesters of biology teacher education. We know from intervention studies that starting with reflective case studies (learning about science) and proceeding with scientific practices (doing science; [67]) could possibly be appropriate [47].

Fourth, to further elicit pre-service teachers' understanding of NOS, it would be fruitful to complement quantitative measures with a qualitative instrument like VNOS [25] to measure understanding of NOS. As mentioned above, it was not possible in this study due to the excess of test time.

Finally, the positive relationship between the frequency of learning opportunities and the understanding of NOS indicates that NOS-related courses should be strengthened during teacher education. A growing number of studies give first hints on how effective courses related to NOS topics could look, e.g., [47,71]. Learning opportunities for scientific practices need to "make the implicit explicit" ([72], p. 113), if they are meant to promote an understanding of NOS. In our analysis of module manuals, most NOS learning opportunities were related to scientific practices. However, promoting scientific practices without explicitly reflecting their function for knowledge generation in science does not promote understanding of NOS [73–75]. It would therefore be ideal to generate a link between these two properties [47]. The didactic modules provide the appropriate framework for linking them: In this way, the theoretical NOS aspects from subject didactics could be merged with the practical NOS parts from laboratory coursework and exercises. It would therefore be helpful to integrate an experimental and methodical part into the subject didactics, e.g., [76].

5. Conclusions

Our findings add an overall positive trend for the effectiveness of NOS learning opportunities to the mixed picture on the development of teacher students' NOS understanding, e.g., [43,45,47], in which (1) teachers' NOS conceptions are not adequate; (2) variables on the academic background have no effect; but (3) at least explicit-reflective approaches improve NOS conceptions (summarised by [8]).

The results of the study are interpreted to the effect that the learning opportunities offered contribute in principle to the promotion of an understanding of NOS among pre-service biology teachers. This means that students at universities with a higher number of NOS-related learning opportunities in the course of their studies also have a higher understanding of NOS. Similar correlations are also evident for the number of semesters, the second subject, and the degree programme.

Overall, however, the relationship between learning opportunities and understanding of NOS remains small. This finding is in line with findings from other subjects, where only a small amount of variance could be explained by institutional factors. The small correlation must therefore be further explained, since further NOS-specific explanations are possible for the small connection of offered learning opportunities and NOS understanding. (1) The NOS-aspects represented in learning opportunities do not sufficiently cover NOS and therefore cannot explain the development of its understanding by students of teaching. Some NOS aspects are more difficult to understand [46], so a combination of reflection on historic case studies and integrated reflection during scientific practices might be useful [47]; (2) The development of understanding of NOS is explained by further factors that are justified in the individual perception of the topic: NOS is perceived differently for motivational and socio-cultural reasons [46]. Therefore, NOS-instruction might fail, if its inclusion into the curriculum is not explained [46].

Despite the limitations mentioned (see Section 4.3), the results show how learning opportunities for NOS are distributed in the course of teacher training at universities and to what extent we can measure their contribution to the understanding of NOS. The following findings can be seen in the summary: Learning opportunities focus strongly on scientific practices and are mainly located in the first semesters of the Bachelor's degree. Learning opportunities stagnate in the following semesters. Notwithstanding, the learning opportunities are related to the development of NOS understanding of the pre-service biology teachers. This relation would be enhanced if further learning opportunities were integrated into the course of biology teacher education.

In order to enable an effective promotion of NOS understanding, more explicit-reflective learning opportunities should be added, especially in the Master's programme. Learning about science, as [67] stated, means complementing content learning with learning opportunities—not exclusively but also—on doing science ("three-phase approach" of "modelling", "guided practice" and "application"; p. 2547) and learning about science through a reflection of NOS in the curricula (e.g., historical case studies, language; [47]). Some effective approaches have already been identified and tested in intervention studies at single universities [47,71]. It is clear from our findings that more of them should be integrated into the curricula in order to enhance the development of NOS understanding.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2227-7102/8/3/103/s1>, Table S1: Synthesis of GA lists as reported in the overviews [20,21], Table S2: Coding scheme for the identification of learning opportunities in module manuals.

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