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Assessing Nature of Science in the Early Study Program *Juniorstudium* of the University of Rostock

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Abstract

A major goal in science education is Scientific Literacy. Nature of Science (NOS) is therefore a widely accepted "core component" of Scientific Literacy and mostly conceptualized in "the consensus framework". Recent results have shown that the understanding of Scientific Literacy is decreasing. Students in all grades also hold naïve conceptions about Nature of Science. These findings are critically questioning the yield of science education. Despite curricular efforts, science lessons seem to be ineffective to adequately teach NOS in school. Early study programs, like the Juniorstudium of the University of Rostock, could possibly help those students who want to study in particular. Initial investigations have shown that former junior-students perform significantly better in their later studies.
At this point, the question arises as to whether the "Juniorstudium" contributes to the development of an appropriate understanding of scientific epistemological beliefs (NOS). Sophisticated epistemological beliefs favor aspects of academic success. An authentic learning environment possibly increases NOS understanding.
The Juniorstudium as a blended-learning, digital format could support science education – also in an extracurricular way, firmly anchored as part of school science in Highschool. Little effort is required to implement the project for schools, because it is run by university and (under)graduates. Lectures were recorded and are supplemented by students and authentic tasks from the respective study program.
An initial pilot assessment delivered acceptable reliability and is therefore an economic instrument to assess NOS for Highschool students quantitatively.

Keywords: *Early Study Program, Epistemological Beliefs, Extracurricular Learning Location, Nature of Science, Scientific Literacy.*

1. Introduction

The scientific and technological transformation of our world is increasingly driving the accumulation of knowledge. This is also reflected in the increasing number of scientific publications worldwide [1]. The influence of science and technology on the world we live in is huge. The COVID-19 crisis in particular has shown that epistemological skills are important for understanding political decisions based on a foundation of dynamic knowledge and therefore are relevant to participate in democracy [2]. It is also important due to high drop-out rates especially in scientific and mathematical studies [3]. So, a crucial question is, what the yields of science education are and if they can be supported by extracurricular learning locations.
The intent of this project is to assess nature of science understanding of upper secondary students (Gymnasium) participating in the early study program *Juniorstudium*. With enrolment rates of over 500 participants per semester, the junior study program is the largest early study program in Germany. Therefore, an efficient, quantitative instrument has to be used for assessment of NOS.
In the following, theoretical considerations are first presented in order to discuss these in the light of previous findings and the early study program called *Juniorstudium*. Then, a first piloting instrument will be presented with initial results.

2. Theoretical Framework

2.1 Scientific Literacy

Scientific Literacy is a main goal in science education and might be "the single most touted goal of science teaching over the last 40 years" [4]. There is a multitude of definitions around this concept used for development of reform documents [5], large scale assessments [6] or new approaches to think about it theoretically [7]. Efforts aimed at fostering a public understanding, and thereby finally defining its meaning has been unsuccessful [4]. In a comprehensive literature analysis by Roberts,

scientific literacy is understood as a continuum with increasing polarization between two extreme poles. These poles are represented by the terms Vision I and Vision II [8].
Vision I (*Science Literacy*) is defined as literacy in relation to the natural sciences, encompassing products, processes, central concepts, and principles. The foundational elements of Vision I delineating encompass basic concepts in science, the nature of science, and ethics that govern the scientist's work. This signifies that it constitutes an internal perspective, often referred to as science without society with the objective of empowering learners to acquire the necessary competencies to engage in advanced science in the future [9, 10].
Vision II (*Scientific Literacy*) emphasizes the application of scientific knowledge in societal contexts. It is an external perspective that aligns with the scientific demands on future citizens. The content of this vision carries personal and social implications. In this sense, scientific literacy signifies the ability to apply scientific knowledge in real-life scenarios, taking into account personal, cultural, and social attitudes, beliefs, and ideologies [8].
More recent concepts add a Vision III (*Critical Science Literacy*) [10], which is about “enabling the individual to apply their basic scientific education not only in individual but also in social contexts” [11]. This requires a critical awareness and a reflexivity aimed at social and ecological justice [12].
However, all these definitions and extensions are also accompanied by a “paralysis” that prevents science educators from “moving forward with a focused vision of what it could, in fact, achieve” [4]. Scientific Literacy might be such a fundamental term in science education which should only be described to the extent that it helps to avoid misunderstandings [13]. So to be clear and give a realistic vision for scientific literacy promoted by the early study program *Juniorstudium*: Based on the fact that the junior study program is primarily aimed at learners who aspire to pursue higher education at a later stage, are interested in acquiring a general understanding of the subject, or simply wish to gain an orientation in the academic environment, this program is closely associated with a vision that emphasize epistemological aspects in science education [8].

2.2 Nature of Science

The natural sciences enable a special way of looking at the world that is relevant for education [14]. In a modern, science-driven and technologically oriented society, an appropriate understanding of science is considered a prerequisite for social participation [15]. An elaborate understanding of science for dealing with epistemic uncertainties appears to be a necessary prerequisite for active participation in a society shaped by science and technology [2, 15].
Nature of Science/Inquiry (NOS/I) is understood as a subset and core component of scientific literacy [16] and refers in the sense of (meta-) reflection in and about the domain of natural sciences [17]. It encompasses the epistemological, scientific-theoretical, scientific-ethical and validity-theoretical foundations of the natural sciences [17] - in short: nature of science describes how science functions [18]. And especially with the rise of misinformation the question of epistemic authority within medial information occurred for all learners. Core elements like epistemic trust, social practices that ensure reliable knowledge and faithful communication are relevant aspects of nature of science [19].
There is a multitude of constructs for describing and assessing NOS. The dominant approach to assess nature of science is the so-called *consensus framework* [16]. It includes more or less eight aspects: Empirical, Inferential, Creative, Theory-Driven, Tentative, Myth of the “Scientific Method”, Scientific theories, Scientific laws, social dimensions of science, social and cultural embeddedness of science [20]. The aspects presented refer to a pragmatic, educational orientation of NOS [21].

2.3 Epistemological Beliefs

Epistemological beliefs can be understood as personal theories about the structure of knowledge and the process of knowing [22]. They relate “to the structure, genesis and validation of knowledge” [23] and are seen as the result of the enculturation process and cognitive demands [24]. Hofer defines epistemological beliefs as “an identifiable set of dimensions of beliefs, organized as theories, progressing in reasonably predictable” [25]. Epistemological beliefs can be based on four core dimensions described below [22].
Nature of knowledge revolves around the status of knowledge, its tentative nature and its development from an absolute to a relativistic and then to a contextual, constructivist view [22]. The dimension *certainty of knowledge* refers to the idea that knowledge is perceived as fixed or changeable [26]. In a naïve position, knowledge is assumed to be absolutist and dual - either true or not. A sophisticated position sees knowledge as uncertain, as something that is relatively true. The dimension *simplicity of knowledge* comprises the question of whether knowledge is more like a collection of facts or more like strongly interrelated concepts [26]. A naïve position holds the view that knowledge consists of

individual facts and unambiguous information. Sophisticated positions view knowledge as being linked and therefore as relative, context-dependent and uncertain [27].
Nature of Knowing includes beliefs about the source of knowledge and justification. It recurs to evaluation of evidence, the role of authority and the process of justification [22]. The dimension *source of knowledge* refers to ideas in which learners receive their knowledge from authorities as opposed to more sophisticated ideas in which learners have the ability to construct knowledge themselves from interactions and various sources [27]. The dimension *justification of knowledge* encompasses ideas that deal with the legitimization of knowledge – whether it is through claims, statements by teachers or experts. It is about dealing with evidence, evaluating expertise and questioning authorities. In naïve views, knowledge claims are considered justified if they are legitimized by observations or arguments of authority. Sophisticated views consider knowledge claims to be justified if they take into account the views of experts, integrate other sources of knowledge and adhere to rules of scientific production and evaluation [28].
Nature of Science revolves around the question of what status scientific knowledge has, how it arises, when it is justified and what factors are immanent in its genesis [17]. It is obvious that the concept is closely related to epistemological beliefs. Nature of Science could be the domain-specific form of scientific epistemological beliefs. Approaches that propagate topic-specificity for epistemological beliefs are also conceivable – therefore the content of NOS might be the domain of natural sciences.

3 Empirical Findings

Considering all preceded theory the question arises why it is useful for upper secondary students to develop sophisticated views about the nature of science. Especially Highschool students are aiming for a study and therefore need well educated resources to successfully reach a degree.

3.1 Secondary Students' Views of NOS

Therefore, there are some results that take (especially German) upper secondary students in focus of investigations. But in addition, they show mixed results. German 12th grade students showed a mixed understanding of scientific inquiry (SI). Summarized, less than 45 % showed an appropriate understanding of all SI aspects [29]. In an international comparison study between German and American secondary students, the U. S. sample held slightly more adequate views of NOS [30]. Related aspects seem to be underrepresented in curriculum and textbooks [16,30,31].
There are several studies that indicate benefits of adequate views of NOS [32]. For example, a high understanding of NOS aspects is accompanied by better problem solving [33] and evaluation of conflicting evidence [34]. Furthermore, several studies on epistemological beliefs have shown that there are positive correlations between epistemological beliefs and for example learning [35], metacognition [36], conceptual change [37], self-regulation [38] or interest [39].

3.2 Student Drop-out in Higher Education

Especially learning related effects are important for the introductory phase of studies. More than 47 % of undergraduate students dropped out of their studies [40]. For first-year science and mathematical students in 2016/2017 who graduated in 2020 the drop-out rate is at 50 % and therefore above average [3]. Reasons for dropping out are multi-causal [40]. Frequently performance problems are mentioned, which might recur to a shift in the intercourse of knowledge and knowing at university in contrast to school science education. Drop-out rates are an important issue in higher (science) education institutions [41]. So called crash courses, repeating the basics of chemistry, biology, physics and mathematics, lead to insufficient knowledge and are no proper response to the problem of high drop-out rates [42].

3.3 Juniorstudium

First results of the early study Program *Juniorstudium* of the University of Rostock indicate more sustainable effects. In a comparative evaluation of an entrance test with 35 questions aimed at mathematical and chemical content 19 out of 23 junior students passed the test while only one out of 22 medicine students (control group) passed. Based on these results, the authors conclude that "if time resources permit, junior study programs are a valuable addition for upper secondary level learners in Germany" [42]. Junior students showed positive tendencies with regard to the independent organization of their learning process. This indicates existing learning strategies, which become even more pronounced through the junior study program [43]. However, this finding must be viewed critically because of their small sample size. Far-reaching conclusions can only be drawn on the basis of further information.

The *Juniorstudium* is an extracurricular learning program aimed primarily at pupils at upper secondary level. It is the biggest early study programs out of 64 in Germany [44]. Even if the concept can be described in principle as a blended learning approach, the main activities take place online, so it is more appropriate to speak of a digital approach [45]. Participation in junior courses lasts one semester (14 weeks).

Junior students have access to digitally recorded introductory lecture videos. In 2023, junior students could access 24 lectures from 6 subject areas. Therefore, it enriches therefore study orientation. The courses are supervised by university students of the respective degree program. They support the students and moderate the learning process by providing and correcting assignments and tests.

During the semester, students must take five cognitive performance tests (two course-specific assignments and two tests as well as a project assignment). In addition, two face-to-face presence events are offered. The first event serves the purpose of social integration and the second meeting refers to course-specific activities in university. Also, junior students are encouraged to participate actively on the online platform *stud.ip*, too.

The *Juniorstudium* could be considered as an authentic learning environment [46], regarding that it might possess an epistemic climate that improves understanding of epistemological aspects like NOS [47].

4 Aims of the Study

Hence, the main research question in this project is whether participation in the *Juniorstudium* leads to more sophisticated views about NOS aspects. In a first step, a quantitative instrument has to be developed, as the *Juniorstudium* shows an annual registration of more than 1000. Theoretical considerations towards the utilized instrument will only be sketched. First results of the piloted instrument will be presented and opposed to first findings of the winter semester 2024/2025 in the *Juniorstudium*.

Q1: Does the utilized instrument permit reliable testing within the group of upper secondary students?
Q2: Are there differences in the understanding of NOS in relation to grade level?
Q3: Do junior students possess more sophisticated views of NOS than upper secondary students?

5 Method

5.1 Available test instruments

The landscape of test instruments to assess students' NOS is diverse and widespread. There has been a shift from forced-choice tests to open-ended qualitative instruments [48]. Firstly, the goal is not to develop a new instrument, but to use scales from existing ones.

The *Understanding of Nature of Science* questionnaire by Kremer (available in German) was developed using an explorative factor analysis according to principal component method with varimax rotation. A seven-factor solution was obtained, reducing the 111 items taken from literature to 44 items. With an overall reliability of α = .84 (separate scales with lower Cronbach's α). This questionnaire was developed to assess scientific epistemological beliefs with 5-point Likert scale [26].

The *questionnaire to assess epistemological beliefs* (FEE) was developed to cover non-represented topics in the discourse of epistemological beliefs. Nine scales could be found by building theoretically based subscales which then were analyzed with an explorative factor analysis. Scales with Cronbach's α < .60 were eliminated. The questionnaire includes 64 items assessed via a 5-point Likert scale [49].

5.2 Test instrument

The development of the utilized instrument can only be sketched due to the given extent in this paper. It is based on the validated *Understanding of Nature of Science* questionnaire, which was developed to assess middle school learners. Lately, it has been applied to assess professors and undergraduate students views of NOS with acceptable results regarding sensitivity as well as reliability [50].

The items have been theoretically reflected towards the structure of epistemological beliefs [22]. They have been regrouped into five dimensions. For example, the dimension *origin* has been supplemented by items of the FEE dimension authority because: a) in terms of content they refer to the *source of knowledge* and b) due to theoretically consideration aspects like authority arguments were missing in the questionnaire by Kremer [26]. Another example is that items of the dimension *development* refer theoretically to the dimension *certainty* (inter-item-correlation showed a value of .544 for dimension *development* and *certainty*) or respectively emphasize an aspect of *justification.* The final instrument possesses 42 items assessed with a five-point Likert scale.

5.3 Sample

Piloting of the questionnaire was conducted in May 2024 with a sample of 187 upper secondary students (uss) from the German state Mecklenburg-Vorpommern. 78 participants attended the tenth grade (41.7 %), 76 attended the eleventh grade (40.6 %) and 33 the twelfth grade (17.7 %). About the half of the students were female (54 %), six were diverse and 42.7 % were male. The students did not receive any compensation or credit. They filled out the survey during their lessons.
The group of junior students (js) in the winter semester 2024/2025 consisted of 415 participants. 95 of them took part in the survey, which is a response rate of 22.8 %. 32 junior students attended the tenth grade (33.6 %), 49 attended eleventh grade (51.5 %) and 14 the twelfth grade (14.9 %). Female participants made up 59 % and male participants 61 % of the survey. Data was collected in September.

5.4 Statistical Tests

In order to reflect quality criteria, the validity of the utilized instrument is based on already validated scales. The interested reader may refer to the qualitative analysis done in original publications.
Reliability will be checked to secure general usability with this sample. Despite the implementation of a diverse sample size, including both middle school learners and professors [50], the interpretation of items by upper secondary students may vary. Secondly, student's beliefs are not consistent stable cognitive traits. It is noteworthy that these beliefs are subject to change [27]; however, a regression is also a possibility [24]. For the second research question there will be a Kruskal-Wallis-Test and for the third research a Mann-Whitney-U-Test [51].

6 Results

6.1 Scale analysis

The standardized Cronbach's α [52] has been utilized. When surveying epistemological beliefs, Cronbach's alpha is usually between .50 and .70 [24]. This phenomenon is attributable to the fact that quantitative instruments are only capable of collecting self-reported information. Epistemological beliefs, in particular, are frequently not reflected and are often unconscious, resulting in a limited α [26]. The cutoff is therefore set to $\alpha < 0.5$. All of the scales are in between the reported range. Only the scale *certainty* possesses a α higher than 0.7.

Scale	Items	Example item	α (uss)	α (js)
Source	7	If you read something in a textbook, you can assume that it is correct. (-)	0.584	0.560
Certainty	10	All questions in the natural sciences have exactly one solution. (-)	0.753	0.805
Justification	14	Good theories are based on the results of many different experiments.	0.696	0.633
Simplicity	5	Scientific theories are often more complicated than they need to be. (-)	0.590	0.645
Creativity	6	Scientific theories and laws have nothing to do with creativity. (-)	0.665	0.709

Table 1: Reliability measure with the standardized Cronbach's α [52] for cohorts of upper secondary students (uss, N=187) and junior students (js, winter semester 24/25, N=95).

6.2 Upper secondary students'

The cohort has been divided into grades. Kremer's report indicated an improvement in NOS understanding with increasing grade level in middle school [53]. Therefore, a Kruskal-Wallis test has been conducted to check whether this result is also valid for upper secondary students. For the scale *source* (χ^2=7.958, df=2, p=0.206) there is no significant correlation. The dimensions *justification* (χ^2=9.551, df=2, p=0.008) and *simplicity* (χ^2=8.562, df=2, p=0.014) show high significant correlations (**). The dimensions *certainty* (χ^2=18.094, df=2, p<0.001) and *creativity* (χ^2=16.941, df=2, p<0.001) show highly significant correlations (***).

Cohort	***10th grade (N=78)***	***11th grade (N=76)***	***12th grade (N=33)***
Scale	***Mean** (SD)*	***Mean** (SD)*	***Mean** (SD)*
Source	***3.47** (0.54)*	***3.61** (0.53)*	***3.67** (0.55)*
Certainty	***3.86** (0.46)*	***4.04** (0.58)*	***4.28** (0.44)*
Justification	***3.8** (0.38)*	***3.9** (0.42)*	***4.03** (0.44)*
Simplicity	***2.94** (0.64)*	***3.17** (0.68)*	***3.31** (0.63)*
Creativity	***3.08** (0.59)*	***3.24** (0.66)*	***3.65** (0.62)*

Table 2: Scale overview for the student sample divided into grades.

6.3 Upper secondary students' and junior students' views

Table 3 shows a comparison of mean scores for each scale of the upper secondary students (uss) and the junior students (js) of the winter semester 2024/2025. A Mann-Whitney-U Test has been conducted to investigate whether there are differences between these two groups. The scale *source* (p=0.57), *simplicity* (p=0.817) and *certainty* (p=0.06) show no significant correlation. The scale *justification* (r=0.14, p=0.013) suggest a significant correlation with a small effect (*). The scale *creativity* (r=0.199, p<0.001) shows a highly significant correlation with a small effect (***).

Cohort	*uss*	*js*
N	*187*	*95*
Scale	***Mean** (SD)*	***Mean** (SD)*
Source	***3.56** (0.54)*	***3.61** (0.51)*
Certainty	***4.01** (0.53)*	***4.12** (0.55)*
Justification	***3.88** (0.42)*	***4.01** (0.32)*
Simplicity	***3.10** (0.67)*	***3.10** (0.64)*
Creativity	***3.25** (0.65)*	***3.54** (0.63)*

Table 3: Comparison of the mean scores between upper secondary students (uss) and junior students of the winter semester 2024/2025.

7 Discussion and Conclusions

In this paper the assessment of nature of science in the early study program *Juniorstudium* has been presented. First results of a pilot instrument have been exposed.
Firstly, the utilized instrument permits acceptable reliability for all scales. It has to be critical reflected, that this statement is only valid under the premise of an acceptable Cronbach's Alpha between 0.5 and 0.7 for the assessment of epistemological beliefs [24]. The reason given refers to self-reported information by the participants which do not have been reflected and are therefore unconscious. The evidence of an underrepresentation of NOS aspects in the curriculum and textbooks might allow this assumption, so it can be considered valid (for the time being).
Secondly, the findings of the present study indicate a positive correlation between grade level and NOS understanding in upper secondary school. It is important to acknowledge the limitations of the sample size, which is inadequate for formulating an evident conclusion. Specifically, the observation that 33 twelfth-grade students could be accommodated within a single classroom underscores the potential for overlooked teacher effects. Nonetheless, the results suggest a first hint that the enhancement of NOS understanding increases also through upper secondary school grades.
Thirdly, initial results have been presented to compare upper secondary students with junior students of the winter semester 2024/2025. The findings indicate that junior students possess a more favorable understanding of aspects subsumed in the scales justification and creativity. Conversely, no substantial disparities were observed in the scales of source, simplicity, and certainty. Though, there are some limitations to these results. Respectively to the results of Q2 it should be investigated whether there are differences according to grade of the students and sample size within the grades. This hasn't been investigated due to a yet too small sample size. Furthermore, the time of investigation must be taken into account. In may the school year is advanced whereas September depicts somehow the start of the school year. This consideration would lead to the assumption that the upper secondary students of the survey should possess higher understanding, which, however, is not the case.
In conclusion, there is more research required to provide first indications with an evidential foundation. The Juniorstudium, however, could support school science education in an epistemological way that is particularly important due to introductory phase of study [3,40,41]. Therefore, the consequently research question must be addressed: does a participation in the Juniorstudium result in an enhanced understanding of NOS?

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