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Adapting the Beliefs about the Nature of Science Questionnaire

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ABSTRACT

Background: Assessing beliefs about the Nature of science presents many problematic issues, frequently involving instruments with limited validity and reliability, unstable dimensions, which limit the replicability of the instrument. **Aim**: In this study, we verify the validity and reliability of the adapted version of the Beliefs about the Nature of Science (BANOS) questionnaire to assess Brazilian science teachers. BANOS proposes to assess the eight NOS aspects outlined in the consensus view. **Design**: The questionnaire was adapted through translation, construct validity testing, and a pilot study. **Data collection and analysis**: In the validation processes, the data were analysed in terms of structural and convergent validity, as well as invariance measurement. Setting and Participants: A total of 388 Brazilian in-service science teachers completed the questionnaire form. **Results**: Results of EFA and CFA indicated a five-factor structure for the BANOS. Invariance measurement at the configural, metric, and scalar levels showed that the questionnaire is equivalent between genders. Additionally, internal consistency factors varied from good to acceptable values (α = 0.82 to 0.62). Teachers demonstrated varying levels of belief in the NOS dimensions. **Conclusions**: The present study supports the notion that the BANOS questionnaire, with five factors, is a valid and reliable instrument.

Keywords: Teachers' beliefs, Nature of Science, Instrument validation, Confirmatory Analysis.

Adaptando o Questionário de Crenças sobre a Natureza da Ciência

RESUMO

Contexto: Avaliar crenças sobre a Natureza da Ciência apresenta muitas questões problemáticas, frequentemente envolvendo instrumentos com validade e confiabilidade limitadas, dimensões instáveis, que também limitam a replicabilidade do instrumento. **Objetivo**: Neste estudo, verificamos a validade e a confiabilidade da versão adaptada do questionário Crenças sobre a Natureza da Ciência (BANOS) para avaliar professores de ciências brasileiros. O BANOS propõe avaliar os oito aspectos

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do NdC descritos na visão consensual. **Design**: O questionário foi adaptado por meio de tradução, testes de validade de construto e um estudo piloto. **Coleta e análise de dados**: Nos processos de validação, os dados foram analisados em termos de validade estrutural e convergente, bem como mensuração de invariância. **Cenário e Participantes**: Um total de 388 professores de ciências em serviço brasileiros completaram o formulário do questionário. Os resultados da AFE e da AFC indicaram uma estrutura de cinco fatores para o BANOS. **Resultados**: A mensuração de invariância nos níveis configural, métrico e escalar mostrou que o questionário é equivalente entre os gêneros. Além disso, os fatores de consistência interna variaram de valores bons a aceitáveis (α = 0,82 a 0,62). Os professores demonstraram níveis variados de crença nas dimensões da NdC. **Conclusões**: O presente estudo corrobora a ideia de que o questionário BANOS, com cinco fatores, é um instrumento válido e confiável.

Palavras-chave: Crenças dos professores, Natureza da ciência, Validação de instrumentos, Análise confirmatória.

INTRODUCTION

Students' scientific literacy is the primary goal of science education (OECD, 2014; 2019). A substantial body of research evidence supports the notion that students' understanding of the Nature of Science (NOS) is essential for achieving scientific literacy (e.g., Lederman et al., 2013; Holbrook & Rannikmae, 2007). However, students' learning is mediated by several factors (Coppi et al., 2024a; Marôco et al., 2024; Tang, 2024), including teachers' knowledge and beliefs of science (Gess-Newsome & Carlson, 2013; Doyle et al., 2018; Kind, 2015). Therefore, science teachers are expected to have a deep understanding of what science is and to hold high levels of NOS beliefs. Thus, gathering information on teachers' beliefs about the NOS may provide evidence to base inferences on regarding ways of teaching science.

However, assessing NOS beliefs presents many problematic issues. First, among the available instruments to assess it, great focus is given to the qualitative approach (Abd-El-Khalick & Lederman, 2023; Chen, 2006). Despite their benefits, qualitative instruments have several limitations, including that they only provide evidence for the assessed context and cannot be extended to a larger population, nor do they allow for the generalisation of the results obtained. These issues, however, can be addressed using quantitative instruments. However, among the available quantitative instruments to assess NOS the main concern is the lack of validity and reliability of these instruments (Abd-El-Khalick, 2014; Abd-El-Khalick & Lederman, 2023; Deng et al., 2011), meaning divergent results by using the same instruments in different samples, low values for internal consistency, or not reporting any proof of validity.

Second, when assessing the NOS, considerable confusion remains among terms such as 'beliefs', 'views', 'perspectives', 'understandings', and 'knowledge'. These terms are frequently misused in instrument titles, leading to misinterpretation of results (Brock & Park, 2022).

Third, the field of NOS deals with a wide range of dimensions that may involve epistemic, cognitive, and social aspects of science. Those dimensions, in turn, may also involve other specific subdimensions that encompass aspects of science enterprise, such as gender, technology development, and environmental issues, among others. At the perspective of the "consensus view" a core list of eight dimensions (Empirical, Inferential, Creative, Theory-driven, Tentative, Myth of the scientific method, Scientific theories & Scientific laws, Social and cultural embeddedness of science) was achieved from a consensus among scientists, science educators and it reasonably provide a starting point to teach, learn and assess NOS in schools (Lederman, 1992; 2007; Abd-El-Khalick et al., 2008; McComas, 2020). While a large list of dimensions can provide a more comprehensive explanation of NOS, the dimensions may not be stable when assessing different samples (e.g. Kaya et al., 2018). A reliable instrument can help identify baseline dimensions of the NOS.

To address these issues, this paper aims to provide evidence on the validity and reliability of an instrument to assess beliefs about the NOS. We adapted and validated the items in the pool of the Beliefs About the Nature of Science (BANOS; Shaakumeni, 2019) with Brazilian in-service science teachers.

In this paper, we first discuss the NOS constructs from the perspective of the consensus view and its alternative perspectives, as well as the issues that affect their assessment. We then present a reliable version of the BANOS questionnaire.

THEORETICAL BACKGROUND

The consensus view of the Nature of Science

Epistemology concerns the nature of human knowledge, and its research field is populated by psychological, philosophical, sociological, and educational perspectives. However, the Nature of Science (NOS) (Lederman, 1992; Abd-El-Khalick, 2014) is commended by science educators as a more intrinsic concept that expresses a specific attention to the nature of scientific knowledge. In Lederman's (2007, p. 833) widely cited definition, "NOS typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development".

The NOS is framed through many perspectives. Alternative frameworks have been created to explain NOS holistically, for instance, the (Reconceptualised) Family Resemblance for NOS (RFN, Irzik & Nola, 2011; Erduram & Dagher, 2014); the Whole of Science (Allchin, 2011; 2012; 2017); or the Feature of Science (Matthews, 2012). A primary perspective on NOS, the consensus view (Abd-El-Khalick, 2012a; 2012b; Abd-El-Khalick & Lederman, 2023), focuses on the essential characteristics of science. These characteristics were identified through theoretical and empirical studies on scientists and science educators' agreement on the meaning of science and on what students should learn about it in schools (Abd-El-Khalick et al., 1998; Abd-El-Khalick et al., 2008; Deng et al., 2011; Lederman et al., 2002; Lederman, 2007; McComas, 2020; McComas & Olson, 1998; Osborne et al., 2003). The consensus view of the NOS comprehends a set of characteristics of science (Lederman, 1992; 2007; Abd-El-Khalick et al., 2008; McComas, 2020) usually described as a list as follows:

- *Empirical* – Scientists access the natural phenomena through observations of the natural world, which is usually filtered by their human senses.
- *Inferential* – Inferences and observations differ. Observations are descriptions of reality. In contrast, inferences are explanations of the phenomena.
- *Creative* – Science benefits from creativity to produce explanations.
- *Theory-driven* – Science is not neutral. Therefore, scientists' work may be influenced by their beliefs, background, prior knowledge, or even by their personal goals, desires, and feelings.
- *Tentative* – Scientific knowledge is not absolute and may evolve with new evidence, technological advancements, and social and cultural needs.
- *Myth of the scientific method* – Although scientists use similar methods and methodologies in science (e.g. raising a research question, observing, hypothesising, conducting an experiment, analysing data, drawing conclusions, disclosing and debating ideas), there is no unique step-by-step method called "the scientific method" which all scientists use. Instead, a nonlinear procedure going back and forth is often practised.
- *Scientific theories & Scientific laws* – Theories and laws differ. Closely related to inferences, theories are explanations of how phenomena occur. A theory is formed on a substantial amount of evidence from diverse disciplines. Theories cannot be directly tested. Laws, in turn, are descriptions of observable phenomena. Furthermore, there is no hierarchy between theory and laws, and one may not become the other.

- *Social and cultural embeddedness of science* – Science and culture are intrinsically bound. So, science can influence and be influenced by the cultural context in any instance (locally or globally).

This set of consensus characteristics has been adopted to categorise views of the NOS. Although critiques have been raised about the consensus view (e.g. Irzik & Nola, 2011; Matthews, 2012), it remains the most widely applied framework in the field (Abd-El-Khalick & Lederman, 2023) due to its didactical and pedagogical utility (e.g. Michel & Neumann, 2016; Niaz, 2015; Papadouris & Constantinou, 2014). The educational relevance of the NOS framework relies on the extent to which science teachers understand the NOS aspects (Aydin, 2014; Supprakob et al., 2016). This understanding, in turn, may shape teachers' beliefs about science and guide instructional practices in the classroom (Bryan, 2012). Furthermore, the set of aspects in the consensus views framework may facilitate the creation of instruments to assess the NOS, as it provides clear categories to anchor such instruments theoretically (Abd-El-Khalick & Lederman, 2023).

The following section provides a brief discussion of quantitative instruments used to assess the NOS.

Assessment of the Nature of Science

Quantitative instruments were very popular in the early years of the science education field in the 1950s, with an emphasis on students' knowledge of science (e.g., Test on Understanding Science, TOUS; Klopfer & Cooley, 1961). Qualitative assessment typically targets improvements in science teaching or learning in small groups and isolated cases. Quantitative assessment can investigate commonalities across constructs of the investigated concept (Fischer et al., 2023). In the last two decades, science educators called for more contextualised assessments, drastically turning the focus of NOS assessment to the qualitative approach (Abd-El-Khalick, 2014; Abd-El-Khalick & Lederman, 2023), with the increasing deployment of instruments such as open-ended questionnaires (e.g. Views of Science-Technology-Society – VOSTS, Aikenhead et al., 1989; Views of the Nature of Science – VNOS, Lederman et al., 2002; Abd-El-Khalick et al., 1998).

From a psychological perspective, quantitative instruments remain popular in assessing scientific beliefs (Greene et al., 2018). When clarifying the criticism of NOS assessment, it is crucial to discuss the difference between knowledge and beliefs of the NOS (Brock & Park, 2022). When assessing the knowledge of the NOS, the aim is to evaluate one's knowledge of science, which implies one's cognitive ability to learn. More commonly, instruments focus on students' knowledge of scientific aspects, typically in a test format with multiple-choice questions, allowing for the use of robust analysis such as Rasch measurement (Coppi et al., 2024b; Harrison et al., 2015) and latent class analysis (Nehring, 2019). In contrast, assessing beliefs about the NOS conveys the capacity to think critically about science and its relationships. In this regard, an individual may or may not have informed knowledge about science, but can justify their beliefs (Brock & Park, 2022). However, there are scarce well-structured quantitative instruments specifically designed to assess NOS beliefs (Abd-El-Khalick, 2014; Abd-El-Khalick & Lederman, 2023).

The Student Understanding of Science and Scientific Inquiry (SUSSI, Liang et al., 2008) assesses multi-dimensional aspects of NOS using Likert-type items. While the SUSSI aims to assess scientific inquiry, its dimensions and items are limited to the NOS aspects (Neumann et al., 2010); this may mislead users. Additionally, assessing the understanding of science would require other item types, such as multiple-choice or open-ended questions.

Current instruments have been mostly dedicated to the social aspects of NOS. The Instrument for Assessing Students' Epistemological Views toward Science (SEVs, Tsai & Liu, 2005) has dimensions (as shown in a factor analysis) including "the role of social negotiation on science community, the invented and creative nature of science, the theory-laden exploration of science, the cultural impacts on science, and the changing and tentative feature of science knowledge" (Tsai & Liu, 2005, p. 1626). The Reconceptualised Family Resemblance Approach to Nature of Science Questionnaire (RFNQ, Kaya et al., 2018) comprises 70 items distributed among three scales: (1) cognitive-epistemic system, (2) social-institutional system and (3) educational applications. Studies applying the RFNQ rely on Cronbach's alpha, which may be affected by the large number of items in its scales, interrater reliability, and descriptive statistics (Azninda et al., 2021; Çilekrenkli & Kaya, 2022; Kaya et al., 2018; Schofield et al., 2023; Takriti et al., 2022), which is not enough to inform on items and dimension consistency. A third questionnaire was developed by Xiao et al. (2024) to assess non-epistemic NOS exclusively. This questionnaire consists of 24 ordered multiple-choice items divided into three scales: (1) internal sociology of science, (2) external sociology of science, and (3) science as a vocation. Several pieces of evidence demonstrating good validity and reliability were provided by Xiao et al. (2024), who also employed Rasch analysis.

Further questionnaires more aligned with the consensus of view are the Myths of Science Questionnaire (MOSQ; Buaraphan, 2009) and the Nature of Science Instrument (NOSI; Hacıeminoğlu et al., 2012). The MOSQ has a set of 14 forced-choice items (agree, uncertain, and disagree) that address scientific knowledge, scientific method, scientists' work and scientific enterprise, status and hierarchical relationship between theory and law, tentativeness of science, creativity, social-cultural influence on science, science as cumulative knowledge, and science and technology. The instrument's validity was established using face and content validity. However, no information is provided about its reliability. Furthermore, the results were interpreted in terms of the frequency and percentage of item responses (Buaraphan, 2009). The NOSI has 13 forced-choice items (wrong, do not know, and right). Factor analyses were used to assess four factors of NOS, and acceptable Cronbach's alpha values were reported: (1) observation and inferences (0.74), tentative NOS (0.76), imagination and creativity (0.80), and empirical NOS (0.63). However, the statistical results for the EFA reveal problematic items with low factor loadings (e.g., Item 13, 0.249 – Scientists may reach different conclusions when looking at the same data), and the factor of observation and inferences has only two items.

With the discussed instruments presenting structure issues, it is doubtful whether they can contribute to the advancement of the field (cf. Abd-El-Khalick & Lederman, 2023). Still, the production of high-quality instruments for NOS assessment may prompt investigations into relationships between NOS beliefs, knowledge, and understanding and science achievement, as well as other science factors.

RESEARCH QUESTIONS

RQ1. What is the evidence of validity and reliability for the BANOS questionnaire?

RQ2. What is the factor structure for the BANOS questionnaire?

METHODOLOGY

Instrument. The BANOS (Shaakumeni, 2019; Appendix A) is a theoretically based item pool developed from the consensus view of the NOS (e.g., Lederman et al., 2002; Lederman & Abd-El-Khalick, 1998; Lederman et al., 2014). The BANOS consists of 30 items, a 5-point Likert-type scale (from 1 = completely disagree to 5 = completely agree), and is intended to serve as a resource for questionnaire construction. Originally written in English, a shorter version of the BANOS questionnaire was constructed in the context of Namibia

(Shaakumeni, 2019; Shaakumeni & Csapó, 2019). However, with the author's permission, the present study adopted the full BANOS item pool to avoid cross-cultural interference.

Although few other closed-ended questionnaires were found in the literature, these were designed to assess students' knowledge of the NOS (e.g. Liang et al., 2008) and/or provide limited evidence of reliability (eg, Takriti et al., 2022). The BANOS aims to target NOS beliefs, and robust statistical evidence has been provided using this instrument (Shaakumeni & Csapó, 2019).

Adaptation phase of the BANOS questionnaire

Translation. The BANOS was translated from English to Brazilian Portuguese by two independent translators who are native speakers of Portuguese. Then, a back-translation was performed by a translation agency. Finally, a synthesised version was created by the two authors of this paper, which could be clear in Portuguese and corresponds to the original version of the BANOS questionnaire. The final Portuguese version of the BANOS questionnaire is available in Appendix A.

Content validity. Three experts from the field of science education joined our committee to validate the translated version of the BANOS. The experts evaluated the clarity of items regarding language. Items 33 (Hypotheses do not become theories that in turn become laws.) and 34 (Theories do not become laws, even with additional evidence.) were indicated by the experts as potentially problematic because they mention two ideas, even though they are complementary. These items were candidates for reversal because they conveyed a misconception regarding the relationship between theories and laws. However, during the validity phase, items 33 and 34 were not deleted or changed because we also wanted to gather participants' feedback. At this phase, adjustments were made to the questionnaire format and the clarity of the invitation letter's text to inform participants better.

Pilot test. The pilot test was conducted on a small sample of 119 science teachers through online administration. Although the BANOS developers did not indicate the need for reverse-coded items (Shaakumeni, 2019), the analysis of the corrected item-total correlation revealed eight items that should be reversed (2, 4, 13, 14, 22, 24, 33, and 34). These items also interfered with the internal reliability of the scales. We discuss the reasons for the reversed items below:

- Items 2 and 4 assess the tentativeness aspect, claiming that science can change with the social and cultural interests. This contrasts with other items in the same scale, which claim that changes in science are influenced by advances in science knowledge and technology.

- Item 13 is a positively worded sentence, while other items in the scale are negatively worded, potentially affecting scale consistency.

- Item 14 emphasises that personal feelings may influence science, while other items in the scale refer to the influences of culture and background.

- Items 22 and 24 are worded in a deterministic manner, suggesting that religion and culture interfere in science, which is a mismatch with the other items in the same scale.

- Items 33 and 34 reflect misconceptions about the relationship between theories and laws.

- The internal consistence values of the eight scales with all the original items varied from good to poor (tentative, 6 items, α = .80; empirical, 5 items, α = .60; scientific method, 3 items, α = .76; subjectivity, 3 items, α = .60; imagination and creativity, 4 items, α = .72; sociocultural, 3 items, α = .72; observations and inferences, 3 items, α = .59; theories and laws, 5 items, α = .41). Despite of the low internal consistence of some scales in the questionnaire, no items were deleted in this phase because of the small sample.

- **Validation phase of the BANOS questionnaire**

Sampling. A convenience sample was adopted to recruit participants for the survey. Teachers were contacted through email, social media and referrals from colleagues. A total of 388 science teachers working in private and public schools at the upper secondary level of the Brazilian education system responded to an online survey. Their participation was voluntary, and their identity was anonymous. Our sample consists of teachers who teach disciplines within the Natural Science field (Chemistry, Physics, Biology) and related topics, such as laboratory practice and robotics. The sample information is presented in Table 1.

Table 1

Sample information

Background information	Sample (N = 388)	
	Frequency	Percentage (%)
Gender		
Male	134	34.5

Female	254	65.5
Teaching Experience		
< 5 years	68	10.6
6–10 years	88	22.7
11–15 years	65	16.8
16–20 years	56	14.4
21–25 years	52	13.4
26–30 years	30	7.7
> 30 years	29	7.5
Education Level		
Bachelor's degree	136	35.1
Specialisation (Lato sensu)*	148	38.1
Master	81	20.9
PhD	23	5.9
Age range		
20–24	5	1.4
25–29	30	8.2
30–39	114	31.1
40–49	134	36.6
50–59	65	17.8
> 60	18	4.9

Note. *Postgraduate specialisation focused on professional development.

Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Doctoral School of Education (DSE), University of Szeged (Approval No. 10/2024). Informed consent was obtained from all participants. The research proposal was evaluated in light of the requirements of the ethical conducts on social research with human subjects of the DSE.

Through this statement, we release exempting Acta Scientiae from any resulting consequences, including full assistance and possible compensation for damages to any research participant, in accordance with Resolution No. 510, of April 7, 2016, of the National Health Council of Brazil.

Data analyses

The data was first analysed to identify missing data and sample information (Table 1). Then, normality data was verified with Mardia's tests (Mardia, 1970), which indicated non-normality. To check the reliability of the BANOS questionnaire, we employed structural, convergent validity and invariance measurement.

To determine the factor structure of BANOS, we first conducted Exploratory Factor Analysis (EFA) using Principal Axis Factor (PAF) and promax rotation (Costello & Osborne, 2005). To verify the data appropriateness for EFA, the Kaiser-Meyer-Olkin (KMO) index was calculated (Kaiser & Rice, 1974). To confirm the yielded structure of BANOS, we employed Confirmatory Factor Analysis (CFA) with the Weighted Least Squares with Mean and Variance Adjustment (WLSMV) estimator, which is robust in treating non-normal data (Finney & DiStefano, 2006; DiStefano & Morgan, 2014). The CFA model fit criterion was set according to several indexes (Chi-square test (χ^2); comparative fit index (CFI $\geq$ 0.90); Tucker-Lewis's index (TLI $\geq$ 0.90); standardised root mean square residual (SRMR < 0.08); and root mean square error of approximation (RMSEA $\leq$ 0.06)) (Hooper et al., 2008; Hu & Bentler, 1999). Composite reliability (CR) and average variance extracted (AVE) were calculated for construct reliability using an Excel table, with set criteria of CR $\geq$ 0.5 and AVE $\geq$ 0.7 (Fornell & Larcker, 1981). Measurement Invariance was verified at (1) the configural level to identify similarity in items' factor loading; (2) the metric level, to identify equality of factors occurring in the gender groups; and (3) the scalar level, to identify mean similarity (Leitgöb et al., 2022; Putnick & Bornstein, 2016). We assessed the reliability of the factors using Cronbach's alpha and McDonald's omega (McNeish, 2017; Malkewitz et al., 2022). All data analyses were handled on SPSS and Mplus.

RESULTS AND ANALYSES

Factor Analyses

Exploratory Factor Analysis. The data were appropriate for factor analysis (KMO = .81). The EFA was performed by applying a principal axis factor estimator with a promax rotation. The first EFA yielded 10 factors based on eigenvalues. Since a structure with eight factors was expected in the BANOS questionnaire, a second EFA was conducted with eight fixed factors to verify if this pattern occurred. However, some items loaded in a different factor or were freestanding. Then, exploratorily, we performed several EFAs to find a theoretically and statistically acceptable version of the BANOS. At this phase, items were excluded (Appendix B). We adopted the following items exclusion criteria: (a) Items with low factor loadings (< .4), (b) low commonality (< .3), (c) high cross-loading (> .4) on at least two factors, and (d) items that free-stand or a factor with less than three items (Fabrigar et al., 1999; Costello & Osborne, 2005). In addition, the internal consistency reliabilities (Cronbach's alpha, corrected item-total correlation, and inter-item correlation matrix) were also consulted to delete items. According to the exclusion criteria, 19 items were deleted from the analysis (Items: 2, 4, 6, 7, 8, 9, 10, 14, 15, 16, 20, 21, 22, 26, 27, 28, 33, 34, 35). Some of those items showed statistically high factor loadings in the EFA results. However, because they loaded in pairs, they had to be excluded (see Appendix B).

A structure with five factors was identified as the most appropriate version of the BANOS based on the EFA results. The five factors correspond to the tentativeness, scientific methods, imagination and creativity, sociocultural, and theory and law dimensions. In this structure, item factor loadings were greater than 0.4 and greater than 0.3 for commonality. The lowest commonality was found for item 19 (.34), item 31 (.34), and item 32 (.31). The results of the Bartlett test were significant, $p < .001$. Finally, the factor solution derived from this analysis accounted for 65.73 % of the variation in the data. The factor loadings for the items are shown in Table 2.

Table 2

Pattern matrix of the exploratory factor analysis with the retained items of BANOS

Items	Factors				
	1	2	3	4	5
Tentative					
1. Scientific knowledge changes as we learn more about the natural world.	.798	-.035	.027	-.023	-.094
3. Scientific knowledge changes as scientists reconsider existing evidence.	.561	-.013	-.069	.094	.054
5. Scientific knowledge changes due to advances in technology.	.687	.073	.035	.003	.062
Scientific Method					
11. Scientists do not use a single procedure called the scientific method.	.093	.711	-.037	-.020	-.056
12. There is no single step-by-step scientific method that all scientists follow.	-.025	.934	.031	-.003	.069
13. Scientists use various methods in search of scientific knowledge.	-.054	-.649	-.022	.020	-.035
Imagination and Creativity in Science					

17. Scientists use their creativity to analyse data.	-.010	.006	.937	-.061	.027
18. Scientists use their creativity to interpret data.	.059	.008	.892	.016	-.039
19. Scientists use their creativity to invent explanations.	-.055	-.044	.525	.122	.024
Sociocultural					
23. Science is influenced by economic factors (e.g., research funding).	.157	-.049	-.088	.559	.060
24. The values of the culture determine how science is practised.	-.004	.034	.089	.818	-.029
25. Science is influenced by cultures.	-.047	-.004	.026	.910	-.004
Theories & Laws					
29. There is a difference between scientific theories and laws.	.108	.026	-.080	.033	.431
30. Scientific theories are inferred explanations of observable phenomena.	-.048	-.025	.026	.008	.510
31. Scientific theories and laws are different kinds of scientific knowledge.	-.096	.027	-.003	.048	.592
32. Scientific laws are descriptions of relationships among observable phenomena.	.122	-.067	.074	-.105	.481

Note. The extraction method is Principal Axis Factoring. The rotation method is Promax with Kaiser Normalisation. Items are numbered according to the original version of the BANOS questionnaire.

Confirmatory Factor Analysis. A CFA with WLSM estimator was run to test the confirmability of the five scales. All factor loadings were greater than 0.50. Additionally, all latent factors showed significant correlations. The model showed good fit (X^2 / df = 323.763 / 94, $p < .001$, CFI = .97, TLI = .96, SRMR = .04, RMSEA = .08). Alternative CFA models were assessed for BANOS. The five and four-factor models revealed the best good fit. However, the five-factor model was retained, as the four-factor model may oversimplify the model with no significant difference in goodness of fit. All CFA models are presented in Table 3. The five-factor structure confirmed by the CFA is represented in Figure 1.

Table 3

Alternative model structures for the BANOS

Model	χ^2	df	*p*	CFI	TLI	SRMR	RMSEA (95% CI)
Single factor	2700.071	104	< .001	0.63	0.57	0.15	0.26 [0.254, 0.271]
Uncorrelated five-factors	1284.155	104	< .001	0.83	0.80	0.15	0.17 [0.168, 0.186]
Five-factors	323.763	94	< .001	0.97	0.96	0.04	0.08 [0.072, 0.092]
Four-factor	6542.378	66	< .001	0.98	0.97	0.04	0.08 [0.074, 0.101]

Note. *χ^2 = chi-square; df = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; SRMR = Standardized Root Mean Square Residual; RMSEA = Root Mean Square Error of Approximation.*

Measurement Invariance

Measurement invariance was calculated for the three levels — configural, metric, and scalar — as shown in Table 4. At the configural level, the invariance measure showed that all five factors of the Portuguese BANOS questionnaire are equivalent between genders. At the item level, the metric invariance shows that each item is similarly relevant to the factors across the female and male groups. At the mean level, the scalar invariance showed that the means in all five factors of the BANOS are equivalent between the male and female groups.

Table 4.

Goodness-of-fit indices for measurement invariance across gender

Model	χ^2	df	*p*	CFI	TLI	SRMR	RMSEA (95% CI)
Configural	444.25	188	< .001	0.967	0.957	0.056	0.084 [0.074, 0.094]
Metric	439.68	199	< .001	0.969	0.962	0.056	0.079 [0.069, 0.089]
Scalar	460.29	239	< .001	0.971	0.971	0.056	0.069 [0.060, 0.079]

Note. *χ^2 = chi-square; df = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; SRMR = Standardized Root Mean Square Residual; RMSEA = Root Mean Square Error of Approximation.*

Table 5 shows that the difference in the measured invariance levels slightly improves the model.

Table 5

Fit Indices differences between Invariance Models

Comparison	$\Delta\chi^2$ (*Δdf*)	*p*	ΔCFI	ΔRMSEA
Metric - Configural	7.238 (11)	0.780	0.002	-0.005
Scalar - Metric	33.223 (40)	0.767	0.002	-0.010

Note. p ≤ .05, invariance is supported.

Internal consistency and descriptive analyses

Construct validity. The construct validity of the five-factor model for BANOS was demonstrated to be good for the tentative (AVE = .64, CR = .84), scientific method (AVE = .86, CR = .68), imagination and creativity (AVE = .86, CR = .68), and sociocultural dimensions (AVE = .88, CR = .71). However, the theory and law dimension presented low composite reliability (AVE = .71, CR = .38).

Descriptive. Table 6 presents values for internal consistency, means, standard deviations and correlations. The internal consistency of the remaining factors ranged from acceptable to good reliability. Mean values indicate that teachers hold informed beliefs about the tentativeness characteristics of science. In contrast, teachers hold naïve beliefs about the myth of "the scientific method". The mean values regarding sociocultural aspects of science and differences between theories and laws were around the mid-point (Table 6). Overall, the Spearman correlations revealed weak relationships among the five factors.

Table 6

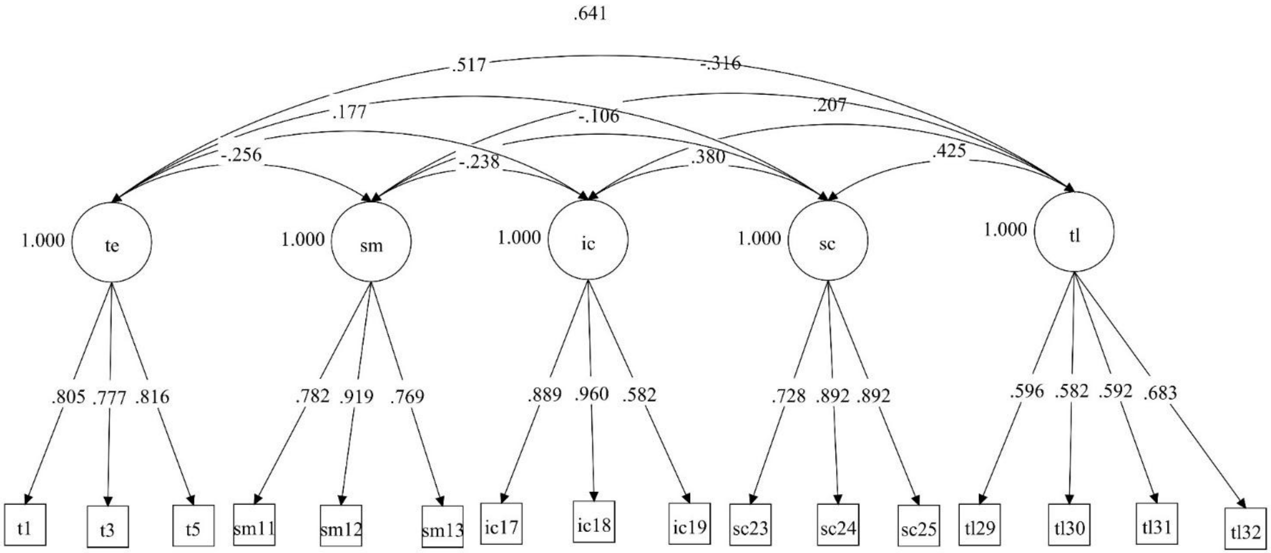
Internal consistency, descriptive and correlation results for the adapted BANOS (N = 388)

Scale	Items	α	ω	*M*	*SD*	1	2	3	4	5
1. Tentative	3	.74	.73	4.15	.66	-				
2. Scientific Method	3	.82	.80	2.47	.96	-.198**	-			
3. Imagination and creativity	4	.81	.80	2.99	1.06	.138**	-.225**	-		
4. Sociocultural	5	.80	.80	3.49	.97	.426**	-.103*	.308**	-	
5. Theory and law	4	.64	.64	3.81	.56	.346**	-.213**	.158**	.264**	-

*Note. α = Cronbach's alpha, ω = McDonald's omega, M = mean, SD = standard deviation. *p < 0.05, **p < 0.001. All dimensions are significantly correlated.*

Figure 1

Confirmatory factor analysis for the BANOS questionnaire



Note. Only standardised and estimated values are displayed in the figure.

Variance errors are not displayed for the WLSM estimator in Mplus.

t = Tentative; sm = Scientific Method; ic = Imagination and Creativity; sc = Sociocultural; tl = Theory and Law.

DISCUSSION

In this paper, we proposed a version of the BANOS questionnaire by adapting and validating the item pool with evidence based on a sample of Brazilian in-service science teachers. The analyses revealed that the BANOS structure consisted of 16 items and five factors. The five-factor structure identified in this research demonstrated good to acceptable reliability. Theoretically, the NOS encompasses numerous dimensions in an extensive range of scientific aspects. The consensus view considers at least seven dimensions (empirical, inferential, creativity, theory-driven, tentative, the myth of the scientific method, scientific theories and scientific laws, and the social and cultural embeddedness of science) (Lederman, 1992, 2007; Abd-El-Khalick et al., 2008; McComas, 2012). Therefore, when researchers develop instruments, such as the BANOS, in alignment with this perspective, they propose items related to these dimensions. However, our results could only confirm five factors: imagination and creativity, tentativeness, sociocultural aspects, the scientific method, and theory and law. Shaakumeni and Csapó's (2019) study with the Namibian science teacher sample also revealed five factors (empirical, tentativeness, scientific method, sociocultural, and subjectivity). Using the SEV questionnaire, Tsai and Liu (2005) also found a five-factor structure (social negotiation, creativity, theory-laden, cultural impacts, and tentativeness). Among these instruments, the imagination and creativity, tentativeness, and sociocultural dimensions consistently appear, indicating replicability.

Correlation patterns of the five BANOS factors demonstrated convergent validity. Overall, the Spearman correlation results showed weak correlations. Moderate correlations were observed, on the one hand, between tentativeness and sociocultural ($r = .43$, $p < 0.01$), and theory and law ($r = .35$, $p < 0.01$), and, on the other hand, between imagination and creativity and the sociocultural dimension ($r = .31$, $p < 0.01$).

The five factors confirmed in our analyses can be divided into two broad categories (Brock & Park, 2022). (1) Belief-driven aspects, such as imagination and creativity, tentativeness, and sociocultural factors. Items of these dimensions involve metaphysical, contextual, historical, and sociological interpretations of the NOS (e.g. Item 24 - The values of the culture determine how science is practised). (2) Knowledge-driven aspects, such as the scientific method, and theory and law. Items in this group would require respondents to have some degree of knowledge (e.g. Item 30 - Scientific theories are inferred explanations of observable phenomena). The empirical and inference dimensions, which were not confirmed in the BANOS structure in our results, may be more aligned with the NOS understanding due to the need for a connection between justified beliefs.

Assessing the NOS encompasses many layers and intersections. For example, the tentative dimension states that scientific knowledge changes; however, science may change in consonance with cultural, social aspects, advances in technology, and discoveries of knowledge. Each of these aspects would constitute a subdimension anchored to the tentativeness of science dimensions, as they infer a different cause (Dagher & Erduram, 2016). In this sense, a significant number of constructs can be considered components of the NOS. However, in practice, assessment instruments are often limited, targeting only a few aspects.

Teachers in the sample demonstrated being at more informed levels regarding the tentative aspect of science, meaning that teachers believe science changes as new evidence is gathered. Teachers also have informed beliefs about the theories and laws dimension, and may be able to differentiate between them. Teachers have a transitional level of beliefs about the sociocultural aspects of science and the role of imagination and creativity in science. These, respectively, may indicate uncertainty about how economic factors and cultural values influence scientific practices, and how imagination or creativity is utilised in the scientific process. Lederman (2007) discusses the consistency in the inconsistency of the results obtained on the assessment of NOS. Teachers express naïve, transitional, or informed views on different aspects in various situations, and a consistent pattern should not be expected. To improve teachers' knowledge, understanding and beliefs on NOS aspects requires coordinated efforts in different approaches, such as promoting professional development programs on this matter for in-service teachers and effectively including topics of NOS on educational courses (Lederman, 1992; Lederman & Lederman, 2014), boosting didactical materials with explicit approaches on the NOS. Other initiatives, such as curriculum emphasis and high-stakes assessments, may act as incentives for teachers to learn and teach the NOS in the classroom (Lederman & Lederman, 2019).

Obtaining a reliable and valid questionnaire that assesses the NOS can impact and improve the assessment of science teachers on a large scale for diagnostic and professional development purposes (Abd-El-Khalick, 2014).

CONCLUSIONS & LIMITATIONS

In this study, we contribute to the academic field by providing a valid and reliable version of the BANOS questionnaire, administered to a sample of in-service Brazilian science teachers. The five-factor structure we found in our study may inform a baseline of constructs for the NOS in the consensus view perspective. The BANOS questionnaire may be helpful for diagnostic assessment to identify teachers' and students' beliefs about the NOS, as well as changes in beliefs resulting from a workshop or intervention, provided that appropriate statistical analyses are employed. The questionnaire may also be used in conjunction with other instruments to assess the effects of beliefs about the NOS on other science education factors, such as teaching efficacy and students' outcomes.

Nevertheless, our study also presents limitations, such as the use of a convenience sampling strategy and the voluntary participation of a targeted sample, specifically in-service science teachers. Future research should build on these findings by testing the questionnaire structure with a larger and more diverse sample, including students and pre-service teachers. It may provide more evidence on the stability of the questionnaire and the replicability of its factors across groups. As a self-report instrument, the data obtained from the BANOS questionnaire may be susceptible to biased responses.

The items of the BANOS questionnaire were theoretically driven. To obtain direct insights from the assessed sample, the BANOS can be used in combination with other instruments for data triangulation. In this study, the final version of the BANOS assesses five dimensions of NOS and may not be suitable for those interested in a more comprehensive set of NOS aspects.

AUTHORS' CONTRIBUTIONS STATEMENTS

S.S.P. was responsible for conceptualisation, methodology, formal analysis, writing – original draft, review and editing, validation, and visualisation. *E.K.M.* supervised, wrote the original draft, conducted reviews and edits, and secured funding. All authors actively participated in the discussion of the results, reviewed and approved the final version of the work.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

CONSENT FOR PUBLICATION

All authors agreed with the content of the manuscript and gave their consent for publication.

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