



DIAGNOSTIC ASSESSMENT OF LOWER-SECONDARY SCHOOL STUDENTS' LEARNING NEEDS RELATED TO POLAR TOPICS: SCALE DEVELOPMENT AND VALIDATION

Abstract. *Rapid polar change makes it important for science teachers to know what students need when they study these regions. This study reports the development and validation of the Polar Topics Learning Needs Scale (PPLS), a self-report instrument for lower-secondary school students. The scale covers five dimensions: Content Learning Needs, Perceived Conceptual Difficulties, Teaching Support Needs, Technology and Activity-Based Learning Preferences, and Interest and Curiosity in Polar Topics. An initial pool of 35 items was reviewed by nine experts ($CVR \geq .78$) and piloted with 25 students. Exploratory factor analysis with 316 students produced five factors that accounted for 53.81% of the variance, with loadings between .46 and .88. Confirmatory factor analysis with a separate group of 204 students supported this structure, $\chi^2(265) = 422.47, p < .001, \chi^2/df = 1.59, RMSEA = .054, SRMR = .06, CFI = .98, NFI = .95, NNFI = .98, GFI = .84$. Subscale α and ω coefficients ranged from .82 to .88. The 25-item PPLS yields subscale scores that can be used descriptively with similar samples; predictive validity, temporal stability, and cross-cultural generalisability have not yet been established.*

Keywords: *climate literacy, learning needs assessment, lower-secondary school students, polar education, scale development, science education*

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Introduction

Polar ecosystems are changing rapidly, and science educators increasingly need to know what students understand about these regions and what they still need to learn. Climate change is widely regarded as one of the central problems of this century, and schools are expected to prepare young people to make informed decisions about it. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), keeping warming within safe limits calls for rapid and far-reaching change in every sector of society, and education is one of the means through which such change can be supported. In line with this, the PISA 2025 Science Framework gives a prominent place to climate change and environmental sustainability (OECD, 2026) and introduces the notion of agency, that is, learners' readiness and capacity to take part in climate-related action (White et al., 2023).

The polar regions hold a special place within the climate system. Both the Arctic and the Antarctic respond quickly to global warming; Rantanen et al. (2022) have shown that the Arctic has warmed almost four times as fast as the planet as a whole since 1979. This Arctic amplification affects weather systems, sea level, ocean circulation, and biodiversity far beyond the region itself (Callaghan et al., 2011). Snow and ice also shape the Earth's energy budget through albedo, store a large share of the planet's fresh water, and sustain ecosystems that are adapted to extreme cold (Barry, 2002). Changes at the poles therefore have consequences for weather, ocean currents, and coastal populations in every part of the world. Although few students will ever visit the Arctic or Antarctica, what happens there bears directly on their lives, and polar literacy is a necessary part of climate education.



Many countries have responded by developing polar education and outreach programmes. Xavier et al. (2024) have reviewed the activities reported by the Antarctic Treaty Parties and found that they deal with climate change, biodiversity, environmental protection, and the history of polar exploration, and that they target groups ranging from primary pupils to adult audiences. Such programmes rest on the assumption that polar themes can open the way to wider climate and environmental learning: polar animals, visible ice loss, and stories of expeditions are all likely to attract young learners' attention.

Frameworks for climate and environmental education have also changed. Earlier approaches concentrated on transmitting knowledge, whereas more recent ones combine cognitive, affective, and behavioural goals. Cantell et al. (2019) have described climate change education with a "bicycle model" in which knowledge and action form the two wheels and hope and agency form the frame that holds them together; in this model, understanding the science is not sufficient unless learners also believe that they can contribute to solutions. Clark (2024) has proposed "critical climate awareness" as an outcome of science education and argues that students should also examine the social, political, and economic sides of climate change, including questions of justice and power. Garrecht et al. (2026) have shown that students' willingness to act on climate change depends jointly on their climate knowledge, environmental values, self-efficacy, and perceived behavioural control. Taken together, these studies suggest that climate education, and research on it, has to address several aspects of learning at once.

Polar literacy has been defined in a similar way. McDonnell et al. (2020) have formulated a set of polar literacy principles that describe what students should know about the polar regions, such as their role in the climate system, their ecosystems, their sensitivity to warming, and the value of polar research. These principles specify the content of polar education. They do not, however, tell teachers what their own students already know, which ideas they find hard, how they like to learn, or what interests them. Moving from principles to classroom practice therefore requires information about learners as well as about content.

Research on climate-related concepts has repeatedly documented learning difficulties. Schubatzky et al. (2024) have found that many students hold fragmented and internally inconsistent ideas about the greenhouse effect and often confuse it with ozone depletion or air pollution. Such difficulties are linked to the nature of the climate system, which consists of many interacting parts, feedback loops, and non-linear processes (Shepardson et al., 2012). In a systematic review, Wildbichler et al. (2025) have identified recurring alternative conceptions about how the greenhouse effect works, how individual greenhouse gases contribute to it, and how weather differs from climate. These findings show why teachers need diagnostic information about the specific ideas their students struggle with, so that teaching can be planned accordingly.

Interest is another factor that shapes how students engage with climate and polar content. In a study with Turkish lower-secondary students, Ergün (2019) has reported that interest in STEM careers differs by gender and grade level, with boys and younger students showing higher interest. Interest is not fixed; it can be developed through suitable teaching and meaningful learning experiences (Linnenbrink-Garcia et al., 2013; Romine et al., 2020). Knowing which aspects of polar topics students already find interesting can help teachers plan lessons that build on that interest.

Science education researchers have developed many instruments to measure what students know and how they reason. He et al. (2022) have designed a two-tier diagnostic test on chemical equilibrium in aqueous solutions for upper-secondary students; because the second tier asks for reasons, the test reveals the thinking behind an answer rather than only whether it is correct. Maghfiroh et al. (2025) have developed a genetics literacy test that assesses reasoning and the application of genetic concepts to real-world issues in addition to factual knowledge. Yalgin et al. (2023) have constructed an attitude scale for science and technology courses and thereby drawn attention to affective outcomes. These studies illustrate the value of carefully validated instruments for both research and classroom practice.

Instruments for climate change education in particular have also been reported. Kim et al. (2024) have compared the climate change awareness of primary school students in Korea and Indonesia and observed clear differences between the two countries, which points to the influence of cultural and educational context. Nepras et al. (2023) have examined climate change attitudes, connection to nature, and pro-environmental behaviour among students in three European countries and reported links between these cognitive, affective, and behavioural variables. Alp and Coşkun Onan (2023) have used comics in science lessons on climate change and analysed the solutions and aesthetic responses that students produced. This body of work indicates that climate learning has several facets and that assessment should reflect them.

Environmental issues have been assessed from an interdisciplinary angle as well. Lan et al. (2021) have developed an instrument that measures how well upper-secondary students combine knowledge from different disciplines when they reason about environmental problems. This view is especially relevant to polar education, since explaining polar change draws on climatology, oceanography, glaciology, ecology, and other fields. Assessment in this area therefore has to consider whether students can connect ideas across subjects and see how different parts of the Earth system interact.

In spite of this research, no validated instrument appears to have been reported that measures lower-secondary students' self-reported learning needs regarding polar topics. This absence matters because polar science poses particular challenges at this age. The Arctic and Antarctic are far removed from students' everyday experience, which makes it hard for them to link polar change to local or global consequences. Polar topics also require reasoning about interactions between the atmosphere, ocean, cryosphere, and biosphere, about feedback processes, and about change over large spatial and temporal scales. Available instruments mainly measure knowledge, attitudes, or behavioural intentions; none of them treats learning needs as a construct with several components. In this study, learning needs refer to what students want to learn, which ideas they expect to find difficult, what kind of teaching support they think they need, how they prefer to learn, and what makes them curious. Teachers need this kind of information to decide where to provide extra support, and curriculum developers need it when they choose content, representations, technologies, and activities. A diagnostic measure of learning needs can therefore inform both teaching and curriculum design.

Significance of the Study

This study addresses the gap by developing the Polar Topics Learning Needs Scale (PPLS) and examining the validity and reliability of its scores for lower-secondary students. Its contributions are theoretical, methodological, and practical.

From a theoretical perspective, the study links three strands of work: climate literacy, polar literacy, and the diagnosis of learning needs. Climate literacy frameworks describe desirable knowledge and competences, and polar literacy principles describe core polar content. Learning needs add the learner's perspective, namely what students themselves report needing, finding difficult, and preferring. Defining polar learning needs as a construct with five components (content needs, conceptual difficulties, teaching support needs, learning preferences, and interest) provides a basis for needs-based approaches to polar and climate education.

Methodologically, the study follows accepted guidelines for scale development (Boateng et al., 2018; DeVellis & Thorpe, 2021). Expert review, a pilot study, exploratory factor analysis (EFA) with one sample, and confirmatory factor analysis (CFA) with a second, independent sample were used. Testing the EFA structure on different students reduces the risk that the structure merely reflects chance features of a single data set.

In practical terms, the PPLS gives teachers, curriculum developers, and researchers a short tool for identifying students' polar learning needs. A teacher can administer it before a unit on polar topics and adjust lessons to the content gaps, difficulties, and preferences it reveals. Curriculum developers can use it to check whether materials address all five dimensions. Researchers can use it to examine factors related to students' engagement with polar topics; its use as an outcome measure in intervention studies will require evidence that scores are sensitive to change.

Purpose of the Study

The aim of this study was to develop the PPLS and to gather evidence on the content validity, construct validity, and reliability of its scores through a multi-phase validation process.

Research Questions

The following research questions guided the study:

RQ1: What are the content validity ratios of the PPLS items based on expert judgement?

RQ2: What factor structure emerges from exploratory factor analysis of the PPLS?

RQ3: To what extent is the EFA-derived measurement model confirmed in an independent CFA sample?

RQ4: How reliable are the PPLS subscale scores?

Research Methodology

Design

The study was carried out as quantitative scale development and validation research based on established guidelines (Boateng et al., 2018; DeVellis & Thorpe, 2021). The work proceeded in five steps: defining the construct, writing items, expert review, pilot testing, and psychometric analysis. Two independent samples were used. EFA was carried out with the first sample to explore the factor structure, and CFA was carried out with the second sample to test whether that structure held for other students from the same context. This two-sample strategy gives stronger evidence than running both analyses on the same data, but replication in other populations is still required before the results can be generalised.

Scale Development Process

Conceptualisation of the Construct

Construct definition was the first step. On the basis of climate literacy frameworks (Cantell et al., 2019; Clark, 2024; Garrecht et al., 2026), the polar literacy principles (McDonnell et al., 2020), and studies on students' difficulties with climate concepts (Schubatzky et al., 2024; Wildbichler et al., 2025), polar learning needs were defined as a construct made up of several related dimensions. The definition goes beyond the topics students want to study; it also includes the concepts they expect to find difficult, the kinds of teaching support they think they need, the learning modes they prefer, and the aspects of polar topics that interest them. The aim was a diagnostic profile that teachers can use when making teaching decisions.

Needs Analysis and Item Pool Generation

In the second step, the item pool was written. Five sources were used: (1) climate and polar literacy frameworks, to identify key content; (2) research on students' difficulties with climate and polar concepts; (3) existing polar education resources and curricula, to identify common teaching approaches; (4) informal interviews with lower-secondary science teachers ($n = 5$) about their students' needs and difficulties; and (5) focus groups with lower-secondary students ($n = 12$) about their questions, interests, and difficulties concerning the polar regions. This process produced 35 items for five hypothesised dimensions: Content Learning Needs (topics students would like to study), Perceived Conceptual Difficulties (ideas students find hard to understand), Teaching Support Needs (explanations and materials students find helpful), Technology and Activity-Based Learning Preferences (preferred tools and activities), and Interest and Curiosity in Polar Topics (motivational and affective aspects). The items were written in simple language suitable for students aged 10–14, without technical terms or complex sentences.

Content Validity Assessment

Content validity, that is, the degree to which the items represent the intended construct, was examined in the third step. Nine experts reviewed the items: science education researchers ($n = 4$), climate scientists with experience in education and outreach ($n = 3$), and experienced lower-secondary science teachers ($n = 2$). They received the definition of polar learning needs, a description of each dimension, and the 35 items, and they classified each item as "essential", "useful but not essential", or "not necessary". A Content Validity Ratio (CVR) was then computed for each item with Lawshe's (1975) formula, and items below the critical value of .78 for nine experts (Ayre & Scally, 2014) were removed. The experts' written comments on clarity, relevance, and suitability for the age group were used to revise item wording. The results of this step are reported under Research Results; the resulting 30-item draft was used in the pilot study.

Pilot Study

In the fourth step, the 30-item draft was piloted with 25 lower-secondary students. After completing the form, the students took part in short cognitive interviews in which they explained how they understood each item, whether any wording was unclear, and how they interpreted the response options. The interviews showed that

the items were understood as intended and that the five-point Likert format (1 = *Strongly Disagree*, 2 = *Disagree*, 3 = *Neutral*, 4 = *Agree*, 5 = *Strongly Agree*) was easy to use. Completion took about 10–15 minutes, which is feasible within one lesson. As no problems were identified, all 30 items were retained for the main study.

Participants

EFA Sample

The EFA sample comprised 316 lower-secondary students from public schools in Çanakkale, Türkiye. Recommendations on sample size for EFA vary. Kass and Tinsley (1979) recommend five to ten participants per item, Tabachnick and Fidell (2013) regard at least 300 cases as sufficient, and Comrey and Lee (1992) rate samples of 100, 200, 300, 500, and 1,000 as poor, fair, good, very good, and excellent, respectively. By these criteria, a sample of 316 for 30 items is adequate.

Responses were first obtained from 330 students. Fourteen cases were identified as multivariate outliers (Mahalanobis distance) and removed, which left 316. Schools were chosen by convenience sampling, according to accessibility and their willingness to take part. By grade, the sample consisted of 89 fifth graders (28.2%), 114 sixth graders (36.1%), 97 seventh graders (30.7%), and 16 eighth graders (5.1%). There were 153 girls (48.4%) and 163 boys (51.6%), aged 10 to 14. All participants attended regular science lessons that included some climate and environmental content, but the amount of earlier teaching on polar topics differed between schools and classes.

CFA Sample

The CFA sample comprised 204 students from other public schools in Çanakkale. Of the 218 students initially surveyed, 14 multivariate outliers (Mahalanobis distance) were removed. No school or student took part in both samples. This separation gives a stricter test of the EFA structure within the study, although it does not in itself show that the structure generalises to other settings. The sample included 54 fifth graders (26.5%), 77 sixth graders (37.7%), 57 seventh graders (27.9%), and 16 eighth graders (7.8%); 103 were girls (50.5%) and 101 were boys (49.5%). As in the EFA sample, prior exposure to polar topics varied.

Instruments

The final PPLS contains 25 items in five subscales. Items are answered on a five-point scale from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). Depending on the subscale, higher scores indicate stronger learning needs, greater perceived difficulty, stronger preferences, or greater interest (item wording is given in Appendix, Table B):

1. Content Learning Needs (6 items): the wish to learn about the role of the polar regions in Earth's climate, the effects of melting glaciers and ice sheets, the effects of climate change on polar animals, the relationship between polar life and environmental conditions, the aims of polar research, and the global effects of polar change.
2. Perceived Conceptual Difficulties (4 items): difficulty in understanding scientific terms, polar events and processes, the relationship between polar life and climate change, and the differences between the Arctic and the Antarctic.
3. Teaching Support Needs (3 items): the perceived benefit of visual materials, of teacher explanations supported by examples, and of links to everyday life.
4. Technology and Activity-Based Learning Preferences (7 items): a preference for computer-based models and simulations, three-dimensional models, educational games, virtual field trips or virtual reality, animations, maps, and project- or competition-based activities.
5. Interest and Curiosity in Polar Topics (5 items): curiosity about polar organisms, environmental conditions, the lives of people and researchers in polar regions, new developments, and ways of protecting the polar regions.

Data Collection Process

The data were gathered in the spring term of the 2025–2026 school year. The PPLS was given on paper during regular lessons. All classes received the same written directions, students worked individually, and the administrator



answered only procedural questions. Before starting, students were told the aim of the study, that their answers would remain confidential, and that taking part was optional and had no bearing on their marks. Completion took 10–15 minutes.

Data Analysis

Data Preprocessing

Before the factor analyses, the data were checked for missing values and outliers. Missing responses made up 1.73% of the EFA data and 2.25% of the CFA data. Given these low rates, missing values were replaced with the item mean; because this method can reduce variances and correlations, it is noted as a limitation. Univariate outliers were screened with standardised z scores ($|z| > 3.00$), and multivariate outliers with Mahalanobis distance at $p < .001$. Each flagged case was inspected to decide whether it reflected an entry error, careless responding, or a genuine extreme response. On the basis of the multivariate criterion, 14 cases were removed from each sample (EFA: 330 to 316; CFA: 218 to 204). No case was removed because of missing data.

Exploratory Factor Analysis

Before the EFA ($n = 316$), sampling adequacy was checked with the Kaiser–Meyer–Olkin (KMO) statistic and Bartlett's test of sphericity. A KMO value above .90 is regarded as excellent, and a significant Bartlett's test ($p < .05$) shows that the correlations are large enough for factor analysis.

Principal axis factoring (PAF) was chosen as the extraction method because, unlike principal component analysis, it analyses only the variance that items share and is therefore suited to identifying latent factors. Because the dimensions were expected to correlate, the oblique promax rotation was applied. The number of factors was decided on the basis of eigenvalues above 1.0, the scree plot, and interpretability. As the Kaiser criterion alone may retain too many or too few factors, Horn's (1965) parallel analysis was also run, in which the observed eigenvalues are compared with eigenvalues from random data sets of the same size. Parallel analysis indicated three factors, whereas the Kaiser criterion, the scree plot, and the theoretical model developed during construct definition and expert review indicated five. Because the decision should not rest on a single criterion (Fabrigar et al., 1999), and because the five-factor model was later supported by CFA in the independent sample, five factors were retained. This point is taken up again in the Discussion.

An item was kept if its primary loading was at least .40, a common cut-off for salient loadings (Hair et al., 2010), and if no secondary loading came within .10 of the primary loading. Items not meeting these rules were removed one at a time, and the EFA was repeated after each removal. Five items (M14, M16, M22, M24, and M25) were eliminated in this way, which left 25 items on five factors. The EFA was carried out in SPSS 25.0.

Confirmatory Factor Analysis

The five-factor model was tested with CFA in the independent sample ($n = 204$). Each of the 25 items was specified to load only on its own factor, and the factors were allowed to correlate. Robust maximum likelihood estimation was used: the model was estimated from the covariance matrix and its asymptotic covariance matrix, and the Satorra–Bentler scaled χ^2 was applied to correct the test statistic and the fit indices when the data depart from normality (Satorra & Bentler, 1994).

Following Kline (2023), fit was judged from several indices considered together rather than from fixed cut-offs: χ^2/df , RMSEA, SRMR, CFI, NFI, NNFI (TLI), and GFI. The CFA was run in LISREL 8.8.

Reliability Analysis

Reliability was estimated with Cronbach's alpha (α) and McDonald's omega (ω) for each subscale. Because the PPLS is multidimensional, only subscale coefficients are interpreted, and no total score is formed (Boateng et al., 2018). Corrected item–total correlations within each subscale were used as an index of item discrimination, with .40 as the minimum. Since Cappelleri et al. (2014) regard item–scale correlations of about .37 or above as relatively strong, this cut-off is conservative.

Convergent and Discriminant Validity

Convergent and discriminant validity were assessed with the completely standardised CFA solution. For each subscale, the average variance extracted (AVE) and the composite reliability (CR) were derived from the standardised loadings and the error variances. For discriminant validity, the square root of each subscale's AVE was compared with its correlations with the other subscales (Fornell & Larcker, 1981). The heterotrait–monotrait ratio (HTMT) was calculated as a second check (Henseler et al., 2015).

Ethical Considerations

Ethical approval was granted by the Çanakkale Onsekiz Mart University Social and Human Sciences Ethics Committee (approval no. E-80110942-050.99-2500158151-06/86, 26 May 2025). Parents or legal guardians gave written informed consent for every participating student. Students were told that taking part was voluntary, that they could stop at any time without any consequence, and that their answers would be confidential. No names or other identifying information were recorded, and only the research team had access to the data.

Research Results*Content Validity Results*

Of the 35 draft items, 30 reached or exceeded the critical CVR value of .78 for nine experts (Ayre & Scally, 2014); the five items below this value were removed. The mean CVR of the retained items was .89. The experts' written comments led only to minor changes in wording. These results provide content-validity evidence for the 30-item draft form (RQ1).

Exploratory Factor Analysis Results

The KMO value was .94, which indicates excellent sampling adequacy, and Bartlett's test was significant, $\chi^2(435) = 5000.44$, $p < .001$, which shows that the correlation matrix differed from an identity matrix (Table 1).

Table 1*KMO and Bartlett's Test Results*

Measure	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	.94
Bartlett's Test of Sphericity: χ^2	5000.44
<i>df</i>	435
<i>p</i>	< .001

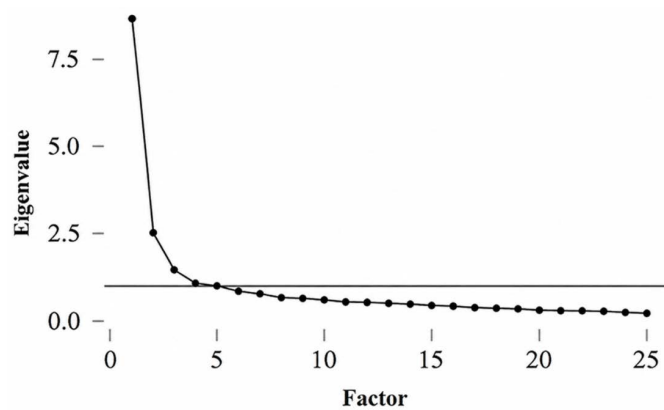
PAF with promax rotation was first applied to the 30-item draft. The eigenvalue criterion, the scree plot, and interpretability pointed to five factors. Five items were then removed one by one: M14 (primary loading = .36) and M16 (.36) loaded below .40, while M22 (.31), M24 (.35), and M25 (.39) also had a secondary loading within .10 of their primary loading. In the final analysis of the remaining 25 items, the five factors were clearly interpretable, and primary loadings ranged from .46 to .88.

For the 25-item solution, the initial eigenvalues of the five factors were 9.55, 2.53, 1.47, 1.08, and 1.02. After extraction, the factors accounted for 53.81% of the total variance: 36.41% for Factor 1, 8.40% for Factor 2, 3.87% for Factor 3, 2.69% for Factor 4, and 2.44% for Factor 5 (Table 2).

Table 2
Factor Eigenvalues and Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Eigenvalue	% of Variance	Cumulative %	Eigenvalue	% of Variance	Cumulative %
1	9.55	38.21	38.21	9.10	36.41	36.41
2	2.53	10.14	48.35	2.10	8.40	44.81
3	1.47	5.88	54.23	0.97	3.87	48.68
4	1.08	4.34	58.56	0.67	2.69	51.37
5	1.02	4.07	62.63	0.61	2.44	53.81

The scree plot (Figure 1) drops steeply between the first and second factors, declines more gradually up to the fifth factor, and flattens after that, which suggests that further factors add little explained variance.

Figure 1
Scree Plot Showing Eigenvalues for Each Factor**Table 3**
Factor Loading Matrix from Exploratory Factor Analysis

Item	CLN	PCD	TSN	TBLP	ICPT
M1	.74				
M2	.71				
M3	.66				
M4	.81				
M5	.61				
M6	.59				
M7		.62			
M8		.85			
M9		.79			
M10		.63			
M11			.58		
M12			.88		



Item	CLN	PCD	TSN	TBLP	ICPT
M13			.64		
M15				.71	
M17				.68	
M18				.60	
M19				.75	
M20				.65	
M21				.46	
M23				.54	
M26					.51
M27					.62
M28					.71
M29					.75
M30					.61
Cronbach's α	.88	.80	.82	.84	.86
McDonald's ω	.88	.81	.82	.85	.87

Note. Only factor loadings $\geq .40$ are displayed. CLN = Content Learning Needs; PCD = Perceived Conceptual Difficulties; TSN = Teaching Support Needs; TBLP = Technology and Activity-Based Learning Preferences; ICPT = Interest and Curiosity in Polar Topics.

Table 3 shows the items assigned to each factor after promax rotation, their loadings, and the reliability coefficients of each factor. The factors were named on the basis of item content, the theoretical framework, and the information collected during item development: Content Learning Needs, Perceived Conceptual Difficulties, Teaching Support Needs, Technology and Activity-Based Learning Preferences, and Interest and Curiosity in Polar Topics. Loadings ranged from .46 to .88.

Internal consistency in the EFA sample was good for all factors: $\alpha = .88$ and $\omega = .88$ for CLN, $\alpha = .80$ and $\omega = .81$ for PCD, $\alpha = .82$ and $\omega = .82$ for TSN, $\alpha = .84$ and $\omega = .85$ for TBLP, and $\alpha = .86$ and $\omega = .87$ for ICPT. All coefficients reached at least .80.

Confirmatory Factor Analysis Results

The 25-item, five-factor model obtained from the EFA was tested in the independent CFA sample ($n = 204$).

Table 4
Confirmatory Factor Analysis Fit Indices

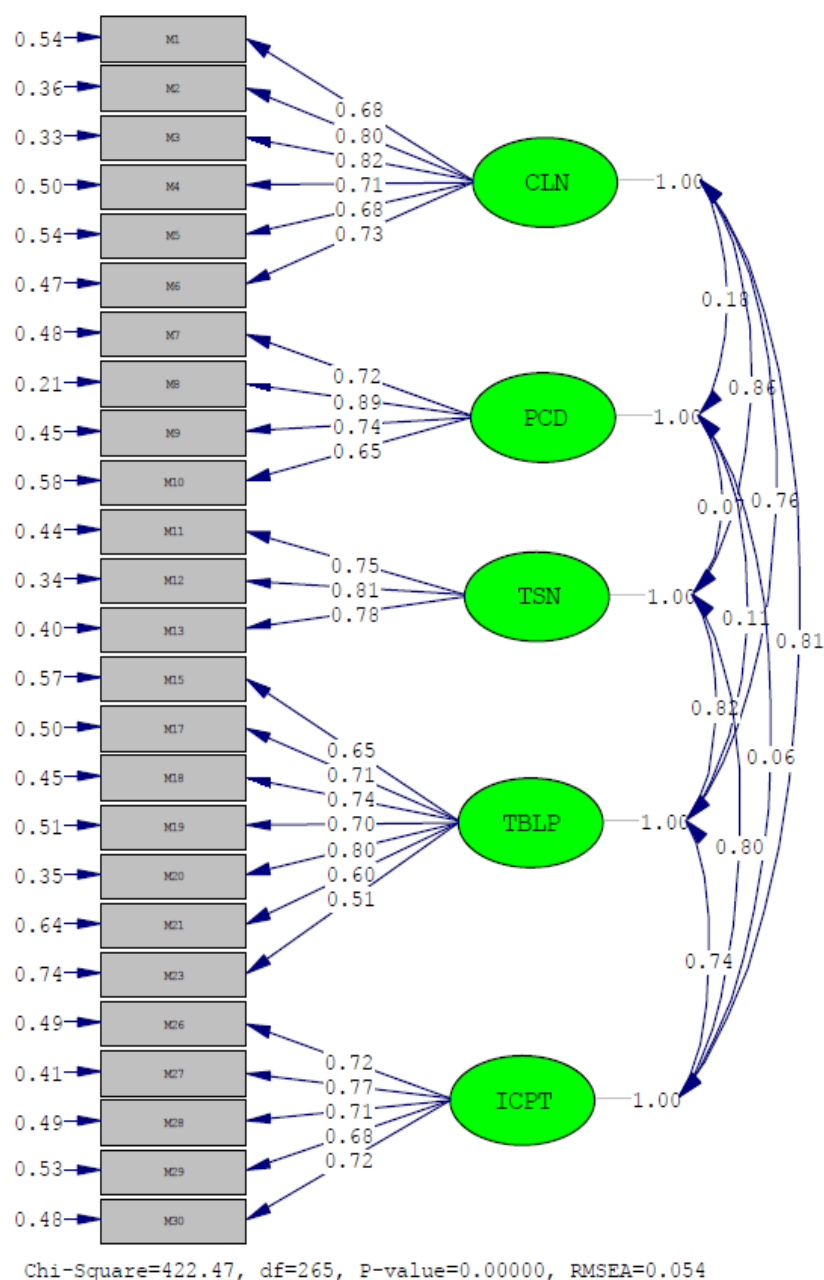
Fit Index	Value	Threshold	Interpretation
χ^2/df	1.59	≤ 2.0	Good fit
RMSEA	.054	$\leq .08$	Acceptable fit
SRMR	.06	$\leq .08$	Good fit
CFI	.98	$\geq .97$	Good fit
NFI	.95	$\geq .95$	Good fit
NNFI	.98	$\geq .97$	Good fit
GFI	.84	$\geq .80$	Acceptable fit

Note. RMSEA = Root Mean Square Error of Approximation; SRMR = Standardised Root Mean Square Residual; CFI = Comparative Fit Index; NFI = Normed Fit Index; NNFI = Non-Normed Fit Index; GFI = Goodness of Fit Index.

Table 4 summarises the fit indices. The χ^2/df ratio was 1.59, RMSEA = .054, 90% CI [.044, .063], SRMR = .06, CFI = .98, NFI = .95, NNFI = .98, and GFI = .84. Overall, the model fitted the data well; RMSEA and GFI were somewhat weaker than the other indices and are therefore interpreted as indicating acceptable rather than good fit.

Figure 2

Standardised Solution of the Five-Factor Confirmatory Factor Analysis Model



Note. Rectangles are observed items, ovals are latent factors, single-headed arrows show standardised factor loadings, and curved double-headed arrows show correlations between factors. All loadings are significant at $p < .05$.

Figure 2 shows the standardised loadings and error variances. All loadings were significant ($p < .05$) and ranged from .51 to .89.

Item Analysis and Reliability

Item-level analyses were conducted with the CFA sample ($n = 204$). Item means ranged from 3.06 to 3.56 and standard deviations from 1.32 to 1.57, which shows that responses were spread across the scale.

Corrected item–total correlations, computed within subscales, ranged from .45 to .76. Every item exceeded the .40 criterion, which indicates that each item is consistent with the other items in its subscale.

Table 5

Item Descriptive Statistics and Reliability Coefficients (CFA Sample, $n = 204$)

Subscale	Item	<i>M</i>	<i>SD</i>	Corrected Item–Total <i>r</i>	Subscale α	Subscale ω
Content Learning Needs	M1	3.29	1.35	.64	.88	.88
	M2	3.38	1.35	.73		
	M3	3.56	1.40	.71		
	M4	3.22	1.32	.68		
	M5	3.30	1.39	.64		
	M6	3.40	1.38	.70		
Perceived Conceptual Difficulties	M7	3.16	1.36	.63	.83	.84
	M8	3.27	1.36	.76		
	M9	3.25	1.39	.67		
	M10	3.17	1.48	.60		
Teaching Support Needs	M11	3.48	1.44	.63	.82	.82
	M12	3.55	1.38	.71		
	M13	3.47	1.41	.68		
Technology and Activity-Based Learning Preferences	M15	3.49	1.49	.63	.85	.85
	M17	3.46	1.52	.67		
	M18	3.37	1.48	.65		
	M19	3.42	1.57	.64		
	M20	3.41	1.40	.72		
	M21	3.18	1.39	.52		
	M23	3.06	1.44	.45		
Interest and Curiosity in Polar Topics	M26	3.38	1.43	.65	.84	.84
	M27	3.31	1.40	.71		
	M28	3.38	1.41	.62		
	M29	3.35	1.34	.63		
	M30	3.30	1.46	.63		

Note. *M* = mean; *SD* = standard deviation; *r* = corrected item–total correlation; α = Cronbach's alpha; ω = McDonald's omega.

Across the five subscales, α ranged from .82 to .88 and ω from .82 to .88 (Table 5). The close agreement between the two coefficients supports the internal consistency of the subscale scores.

*Convergent and Discriminant Validity***Table 6***Convergent Validity (AVE, CR) and Latent Factor Correlations Among the Five PPLS Subscales*

Subscale	AVE	CR	1	2	3	4	5
1. CLN	.545	.88	.738				
2. PCD	.570	.84	.18	.755			
3. TSN	.608	.82	.86*	.07	.780		
4. TBLP	.462	.86	.76*	.11	.82*	.680	
5. ICPT	.519	.84	.81*	.06	.80*	.74*	.720

Note. CLN = Content Learning Needs; PCD = Perceived Conceptual Difficulties; TSN = Teaching Support Needs; TBLP = Technology and Activity-Based Learning Preferences; ICPT = Interest and Curiosity in Polar Topics. Diagonal values are square roots of AVE; values below the diagonal are latent factor correlations. * $p < .05$.

As Table 6 shows, AVE values ranged from .462 to .608 and CR values from .82 to .88, which largely supports convergent validity. The exception was the Technology and Activity-Based Learning Preferences subscale, whose AVE (.462) was slightly below the usual .50 threshold, although its CR (.86) was adequate. Perceived Conceptual Difficulties correlated weakly and non-significantly with the other subscales ($r = .06$ – $.18$, $p > .05$), and the square root of its AVE (.755) exceeded all of these correlations, so the Fornell–Larcker criterion was met for this subscale. The other four subscales correlated strongly with one another ($r = .74$ – $.86$, $p < .05$). For several of these pairs, the correlation was higher than the square root of the AVE of at least one of the two subscales; that is, the Fornell–Larcker criterion was not met. Because the two criteria can lead to different conclusions, HTMT ratios were also examined for all ten pairs (Table 7).

Table 7*Heterotrait-Monotrait Ratio (HTMT) of Correlations Among the Five PPLS Subscales*

	CLN	PCD	TSN	TBLP	ICPT
CLN	1.000				
PCD	.195	1.000			
TSN	.841	.095	1.000		
TBLP	.779	.092	.847	1.000	
ICPT	.825	.051	.801	.774	1.000

HTMT values for pairs that included Perceived Conceptual Difficulties were low (.051–.195). For the other six pairs, they ranged from .774 to .847, below the .85 cut-off suggested by Henseler et al. (2015). Two values, however, were very close to this cut-off: CLN–TSN (.841) and TSN–TBLP (.847). The HTMT results therefore give only qualified support for discriminant validity. The subscales can be distinguished, but four of them overlap considerably, and this overlap should be kept in mind when the scores are interpreted.

Discussion

This study developed the PPLS and collected initial evidence on the validity and reliability of its scores as a self-report measure of lower-secondary students' learning needs regarding polar topics. The five-factor structure found in the EFA was supported by the CFA in an independent sample, and all subscales showed good internal consistency. As the scale is multidimensional, its subscales rather than a total score should be used.

A five-dimensional structure is in line with the current view that assessment in climate and environmental education should cover more than knowledge (Lubej et al., 2025; Martin et al., 2025). The PPLS applies this view

to polar education by describing what students want to learn, what they find hard, what support they need, how they prefer to learn, and what interests them.

Content Learning Needs

Content Learning Needs consists of six items. Its items refer to the climatic role of the polar regions, melting glaciers and ice sheets, the effects of climate change on polar animals, the link between polar life and environmental conditions, the aims of polar research, and the global effects of polar change. These themes correspond to several of the polar literacy principles (McDonnell et al., 2020), and the high loadings (.59–.81) suggest that students see them as parts of one body of knowledge that they would like to acquire.

The cross-national differences reported by Kim et al. (2024) indicate that students' knowledge and learning needs depend on their educational and cultural context. Because polar topics receive limited space in many science curricula, this subscale can show teachers which themes their students most want to study. Given the wide range of topics covered by polar outreach programmes (Xavier et al., 2024), such information can help teachers set priorities while still showing how the topics are connected.

Perceived Conceptual Difficulties

The Perceived Conceptual Difficulties subscale concerns how hard students find scientific terms, polar processes, the relationship between polar life and climate change, and the differences between the Arctic and the Antarctic. These results agree with studies showing that students' ideas about the greenhouse effect are often fragmented (Schubatzky et al., 2024) and that alternative conceptions about climate mechanisms persist (Wildbichler et al., 2025). Polar topics add further demands, such as understanding the ice–albedo feedback and the interactions between the atmosphere, ocean, and cryosphere.

This subscale was only weakly related to the other four ($r = .06$ – $.18$). Students who want to learn more about polar topics, or who are interested in them, do not necessarily expect them to be easy. For teaching, this means that high motivation and high perceived difficulty can occur together; when a class shows both, the teacher can combine engaging content with additional scaffolding. The weak correlations may also partly reflect the fact that the four difficulty items are the only items that describe a problem rather than a wish or a preference. Future studies should examine this possibility.

Unlike two-tier diagnostic tests (He et al., 2022), the PPLS does not measure conceptual understanding directly. It offers complementary information by showing which ideas students themselves consider difficult, and teachers can follow this up with formative assessment of students' actual understanding.

Teaching Support Needs

The Teaching Support Needs subscale covers visual materials, teacher explanations supported by examples, and links to everyday life. Visual representations can help students grasp spatial and temporal patterns that cannot be observed directly, such as seasonal changes in sea ice. Everyday examples can reduce the distance that many students feel from the polar regions.

These preferences are consistent with the meta-analysis by Aeschbach et al. (2025), in which climate education programmes that combined several strategies were more effective than those relying on a single one. They also fit contextual and inquiry-based approaches to environmental literacy (Lestari et al., 2024) and the finding of Teppo et al. (2021) that students' perceptions of teaching approaches are related to their interest in science.

Technology and Activity-Based Learning Preferences

The Technology and Activity-Based Learning Preferences subscale includes computer-based models and simulations, three-dimensional models, educational games, virtual field trips or virtual reality, animations, maps, and project- or competition-based activities. As very few students can visit polar regions, digital tools are one of the main ways of bringing these environments into the classroom (Mulders & Träg, 2023; Pande et al., 2021). Rowe et al. (2025) have shown that guided inquiry modules based on authentic polar data can improve polar literacy.

A preference for a method is not evidence that the method improves learning. Digital tools are useful only when they are aligned with learning goals and supported by appropriate scaffolding. Access to such technology

also differs between schools, so scores on this subscale should be interpreted with the available resources in mind. The relatively low AVE of this subscale (.462) further suggests that its seven items are fairly heterogeneous.

Interest and Curiosity in Polar Topics

The Interest and Curiosity in Polar Topics subscale refers to curiosity about polar organisms, environmental conditions, the lives of people and researchers in polar regions, new developments, and ways of protecting these regions. Neito et al. (2023) have distinguished situational interest, which is triggered by specific learning activities, from more stable individual interest. The PPLS items probably reflect both, since students' current interest may come from earlier lessons as well as from personal curiosity. Ergün (2019) has also shown that interest differs between groups of Turkish lower-secondary students.

Interest is particularly important for climate topics, which can also cause anxiety. Crandon et al. (2022) note that awareness of climate change may lead to anxiety but can also motivate action when young people feel that they can make a difference. Garrecht et al. (2026) have found that willingness to act depends on knowledge, values, self-efficacy, and perceived control, and curiosity about polar topics may be an early step towards these outcomes. The subscale can help teachers identify students who are already interested and those who need more support to become engaged.

Theoretical Contribution

Theoretically, the PPLS connects three lines of work. Climate literacy frameworks such as the bicycle model (Cantell et al., 2019) describe desired knowledge, skills, and dispositions, and polar literacy principles describe core polar content (McDonnell et al., 2020). The learning-needs perspective adds information from learners: what they report needing to learn, where they expect difficulty, what support they prefer, and what interests them.

This perspective questions the assumption that all students in a class need the same content and the same teaching approach. It is consistent with UNESCO's (2024) call for climate education that responds to learners' contexts and needs, and with the emphasis on agency in the PISA 2025 Science Framework (OECD, 2026).

Practical Implications and Recommendations for Use

The PPLS is intended for diagnostic, low-stakes use. The examples below show how it could be used at different levels of the education system. They are recommendations derived from the structure of the scale; their effectiveness was not tested in this study.

Classroom level. A science teacher can give the 25 items (about 10–15 minutes) before a unit that deals with the polar regions or climate change and calculate the class mean for each subscale. If Perceived Conceptual Difficulties is high, more lesson time can be planned for difficult ideas, such as the differences between the Arctic and the Antarctic, and these ideas can be supported with models or analogies. If Teaching Support Needs and Technology and Activity-Based Learning Preferences are high, animations, digital maps, or simulations based on real polar data can be included. Giving the scale again at the end of the unit may show whether the reported needs have changed, although the sensitivity of the scores to change still has to be established.

School level and existing assessment systems. The PPLS can be added to the diagnostic assessments that schools already carry out at the beginning of a school year or a unit, and its results can be recorded together with other entry-level information in the school's assessment and reporting procedures. Science departments can use the class profiles when they prepare their annual and unit plans. Because the scale serves diagnostic purposes, results should be reported as class or group profiles and should not be used for grading or for ranking individual students.

Teacher training. Pre-service science teacher education and in-service training programmes can include short sessions on how to administer the PPLS, how to calculate and read subscale profiles, and how to link each profile to specific teaching strategies. For example, teachers could work with an anonymised class profile and plan a lesson that responds to it. Such training would also help teachers avoid over-interpreting the scores of individual students.

District and curriculum level. Provincial or district education directorates could collect anonymised class-level PPLS profiles from a sample of schools. The combined results could show which polar themes students most want to study, which concepts are widely seen as difficult, and which resources (e.g., simulations or virtual field trips)



are in demand. This information could guide the preparation of local teaching materials, the choice of digital resources, and the planning of teacher training, and it could be passed on to curriculum developers when polar and climate content is revised. Differences in technological resources between schools should be taken into account when such data are compared.

Limitations and Future Research

Several limitations must be noted. First, the number of factors is open to debate. Parallel analysis suggested three factors, whereas the Kaiser criterion, the scree plot, the theoretical model, and the CFA supported five. This difference is consistent with the strong correlations (.74–.86) among four of the subscales and with the clear separation of Perceived Conceptual Difficulties from the others. In addition, the Content Learning Needs and the Interest and Curiosity items are worded in a similar way (“I would like to learn...”), which may have raised the correlation between these two subscales. Future studies should compare the five-factor model with three-factor, bifactor, and higher-order models.

Second, the data came from public schools in one Turkish province, selected by convenience sampling, and eighth graders made up only 5.1% of the EFA sample and 7.8% of the CFA sample. The findings therefore rest mainly on students in Grades 5–7. Replication with larger, more diverse, and grade-balanced samples, including tests of measurement invariance across grades and gender, is needed.

Third, all data were self-reports collected with one instrument at one point in time, which raises the possibility of common method bias. Test–retest reliability was not examined, so the stability of the scores over time is unknown. The PPLS also measures perceived rather than objectively determined needs.

Finally, missing values (1.73% and 2.25%) were replaced by item means. Although the effect is probably small at these rates, future studies should use full information maximum likelihood or multiple imputation.

Conclusions and Implications

This study provides initial evidence that the 25-item PPLS yields valid and reliable subscale scores for describing lower-secondary students' learning needs regarding polar topics. Expert review supported the content of the items, the five-factor structure identified in one sample was confirmed in a second, independent sample, and subscale reliabilities were between .82 and .88. The results also show how the dimensions relate to one another: students' wish to learn about polar topics, their need for support, their preference for technology and activities, and their interest form a closely connected group, whereas their perception of difficulty is largely independent of these. Motivation and perceived difficulty therefore need to be assessed separately.

The main value of the PPLS is that it adds the learner's perspective to content-based frameworks of climate and polar literacy. Used as a low-stakes diagnostic tool, it can help teachers plan units, help schools and education authorities decide on materials and teacher training, and help researchers describe students' needs in polar education.

The study also has clear boundaries. It does not establish the predictive validity of PPLS scores, that is, whether they predict learning, achievement, or engagement. It does not show that the scale works in the same way in other regions, countries, languages, or age groups, because measurement invariance and cross-cultural validity were not tested and the English item wording has not been validated. It provides no evidence on test–retest reliability or on sensitivity to change, and it cannot show that teaching based on PPLS results improves learning. Until such evidence is available, the scale should be used descriptively, and its subscales should be interpreted separately rather than combined into a total score.

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Declaration of Interest

The authors declare no competing interest.

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Appendix: Polar Topics Learning Needs Scale (Lower-Secondary School)**Table A***EFA Factor Loadings, CFA Standardised Factor Loadings and Error Variances, and Item-Retention Decisions*

Dimension	Item	EFA λ	CFA λ	CFA ε	Decision
Factor 1 Content Learning Needs	M1 / Final item 01	.74	.68	.54	Retained
	M2 / Final item 02	.71	.80	.36	Retained
	M3 / Final item 03	.66	.82	.33	Retained
	M4 / Final item 04	.81	.71	.50	Retained
	M5 / Final item 05	.61	.68	.54	Retained
	M6 / Final item 06	.59	.73	.47	Retained
Factor 2 Perceived Conceptual Difficulties	M7 / Final item 07	.62	.72	.48	Retained
	M8 / Final item 08	.85	.89	.21	Retained
	M9 / Final item 09	.79	.74	.45	Retained
	M10 / Final item 10	.63	.65	.58	Retained
Factor 3 Teaching Support Needs	M11 / Final item 11	.58	.75	.44	Retained
	M12 / Final item 12	.88	.81	.34	Retained
	M13 / Final item 13	.64	.78	.40	Retained
	M14	.36	—	—	Removed
Factor 4 Technology and Activity-Based Learning Preferences	M15 / Final item 14	.71	.65	.57	Retained
	M16	.36	—	—	Removed
	M17 / Final item 15	.68	.71	.50	Retained
	M18 / Final item 16	.60	.74	.45	Retained
	M19 / Final item 17	.75	.70	.51	Retained
	M20 / Final item 18	.65	.80	.35	Retained
	M21 / Final item 19	.46	.60	.64	Retained
	M22	.31	—	—	Removed
	M23 / Final item 20	.54	.51	.74	Retained
	M24	.35	—	—	Removed
Factor 5 Interest and Curiosity in Polar Topics	M25	.39	—	—	Removed
	M26 / Final item 21	.51	.72	.49	Retained
	M27 / Final item 22	.62	.77	.41	Retained
	M28 / Final item 23	.71	.71	.49	Retained
	M29 / Final item 24	.75	.68	.53	Retained
	M30 / Final item 25	.61	.72	.48	Retained

Note. λ = factor loading; ε = standardised error variance. Items M14, M16, M22, M24, and M25 were removed during the iterative EFA because they did not meet the retention criteria (primary loading < .40 and/or a secondary loading within .10 of the primary loading); therefore, no CFA values are available for them. For retained items, EFA λ values are the primary loadings in the final EFA solution; for removed items, the loading at the point of removal is shown. "Final item" gives the item number in the 25-item final form.

Table B*Final Items of the Polar Topics Learning Needs Scale (PPLS)*

Dimension	Final item	Original item	Item wording
Content Learning Needs	01	M1	I would like to learn how the polar regions affect Earth's climate.
Content Learning Needs	02	M2	I would like to learn about the consequences of melting glaciers and ice sheets.
Content Learning Needs	03	M3	I would like to learn how polar animals are affected by climate change.
Content Learning Needs	04	M4	I would like to better understand the relationship between life in the polar regions and environmental conditions.
Content Learning Needs	05	M5	I would like to learn about the purposes for which polar research is conducted.
Content Learning Needs	06	M6	I would like to learn how changes occurring in the polar regions affect the world.
Perceived Conceptual Difficulties	07	M7	I find it difficult to understand technical and scientific concepts related to the polar regions.
Perceived Conceptual Difficulties	08	M8	I find it difficult to understand events and processes related to the polar regions.
Perceived Conceptual Difficulties	09	M9	I find it difficult to understand the relationship between life in the polar regions and climate change.
Perceived Conceptual Difficulties	10	M10	I find it difficult to understand the differences between the Arctic and the Antarctic.
Teaching Support Needs	11	M11	I learn better when topics related to the polar regions are supported with visual materials.
Teaching Support Needs	12	M12	I understand polar topics better when my teacher explains them using examples.
Teaching Support Needs	13	M13	I learn polar topics better when they are related to everyday life.
Technology and Activity-Based Learning Preferences	14	M15	When learning about polar topics, I prefer to use computer-based models and simulations.
Technology and Activity-Based Learning Preferences	15	M17	When learning about polar topics, I prefer to use three-dimensional models and applications.
Technology and Activity-Based Learning Preferences	16	M18	When learning about polar topics, I prefer educational games.
Technology and Activity-Based Learning Preferences	17	M19	When learning about the polar regions, I prefer virtual field trips or virtual reality applications.
Technology and Activity-Based Learning Preferences	18	M20	When learning about polar topics, I prefer to use animations.
Technology and Activity-Based Learning Preferences	19	M21	When learning about polar topics, I prefer to work with maps.
Technology and Activity-Based Learning Preferences	20	M23	When learning about polar topics, I prefer project- or competition-based activities.
Interest and Curiosity in Polar Topics	21	M26	I would like to learn more about living organisms in the polar regions.
Interest and Curiosity in Polar Topics	22	M27	I would like to learn more about environmental conditions in the polar regions.
Interest and Curiosity in Polar Topics	23	M28	I am curious about how people and researchers live in the polar regions.
Interest and Curiosity in Polar Topics	24	M29	I would like to keep up with new developments related to the polar regions.
Interest and Curiosity in Polar Topics	25	M30	I am curious about what can be done to protect the polar regions.

Note. The PPLS was originally developed, administered, and psychometrically evaluated in Turkish. The English item wording is provided for reference and reporting purposes. Before the English version is used for data collection or research, appropriate cross-cultural adaptation and psychometric validation should be undertaken.

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