JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

ASSESSING UPPER-SECONDARY SCHOOL STUDENTS' INTERDISCIPLINARY UNDERSTANDING OF ENVIRONMENTAL ISSUES

Yu Lan,
Shaohui Chi,
Zuhao Wang

Abstract. *Science educators have highlighted the need to develop students to integrate knowledge across science disciplines to address real-world issues. However, there has been little research about the development of interdisciplinary assessment instruments. In this research, the instrument that measures the level of upper-secondary school students' interdisciplinary understanding of environmental issues was developed and validated based upon Wilson's Construct Modeling framework. After a pilot testing, the revised assessment instrument of interdisciplinary understanding covering five typical environmental problems comprised 14 multiple-choice questions and four constructed-response questions. Five hundred twenty-three eleventh graders, including 279 boys and 244 girls from mainland China, made up the research sample. The partial credit Rasch analysis has verified the reliability and validity of the interdisciplinary understanding instrument. In addition, the results of cluster analysis revealed that over half of the students could use some partially accurate scientific concepts and principles from two or more disciplinary perspectives to deal with a specific environmental issue. The validated instrument can provide insights for assessing and developing upper-secondary school students' interdisciplinary understanding in science education.*
Keywords: *Environmental Issues, Interdisciplinary Assessment, Interdisciplinary Understanding, Rasch Measurement Model, Science Education*

Yu Lan, Shaohui Chi, Zuhao Wang
East China Normal University, China

Introduction

Dynamic, interconnected, and pressing problems facing our society (e.g., environmental issues) result in the interplay of fields such as sociobiology and chemical ecology. Scientists and non-scientists are alike to be able to integrate knowledge and skills from multiple disciplines to address complex issues. As such, science educators have highlighted the need to develop students to explain phenomena or address problems that span different science disciplines (Jacobs, 1989; Klein, 2015; Mansilla, 2005; Shen et al., 2014; You et al., 2018). That is, students will have to deploy *interdisciplinary understanding*. In addition, scholars have identified many educational benefits of interdisciplinary education, such as developing students' understanding of natural phenomena (You, 2017), enhancing their knowledge integration (Mansilla, 2006), and boosting their deductive reasoning (Golding, 2009; Lattuca et al., 2004).

The premise of an efficient interdisciplinary approach is when student learning outcomes are identified and measured (Kelley & Knowles, 2016; Stevens et al., 2005). Hence, valid and reliable assessment instruments to measure students' interdisciplinary understanding are needed. However, only a few studies have attempted to gauge post-secondary school students' or secondary school students' interdisciplinary understanding (e.g., Shen et al., 2014). Furthermore, there is little research about interdisciplinary instrument designed to assess upper-secondary school students, none of which have reported on the validation process of the assessment. The interdisciplinary efforts that necessitate meta-disciplinary integration vary at different grade levels (Song & Wang, 2021; You, 2017). Thus, there is a need for additional assessment instruments that aim at upper-secondary grade levels.

The research was carried out to develop and validate a new assessment tool for measuring upper-secondary school students' interdisciplinary understanding of environmental issues. Environmental issues were selected as a special context for the instrument because it is closely connected to

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

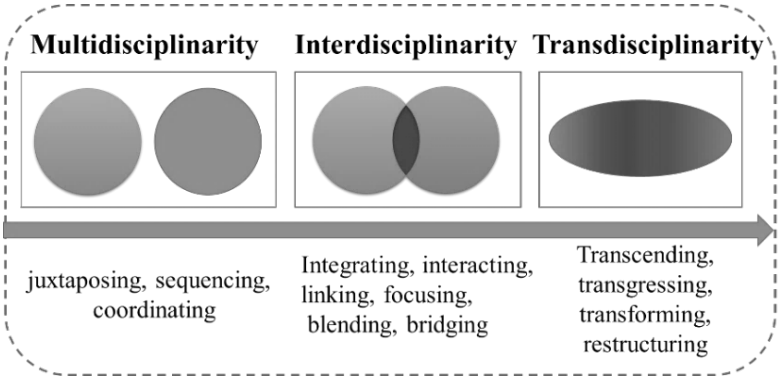
students' lives, which they have experienced in person or through the media. In addition, addressing a rising variety of environmental issues requires an interdisciplinary approach (Stuart, 2016). To put it another way, students need to integrate knowledge from science disciplines of physics, chemistry, biology, and geography to analyze the causes of environmental problems, explore the global impact of environmental issues, and propose measures to address environmental issues.

Literature Review

Multi-, Inter-, and Trans-disciplinarity

Over the years, multi-, inter-, and trans-disciplinarity have been used rhetorically and interchangeably (Ito et al., 2020). It is critical to clarify similarities and differences among the three terms before putting them into use. Figure 1 depicts a theoretical layout illustrating the vital properties of multi-, inter-, and trans-disciplinarity.

Figure 1
The Critical Properties of Multi-, Inter, and Trans-disciplinarity (after Klein, 2010)



Multidisciplinarity is a collection of disciplines. The elements of each discipline in the multi-discipline maintain the parallel and cumulative relationship and maintain a clear discipline boundary (Bruce et al., 2004; Wagner et al., 2011).

Interdisciplinary approaches are to integrate different disciplinary perspectives to provide systematic results. Methods, designs, and outcomes that have been transferred are not restricted to a single domain but the interplay of many domains (Aboelela et al., 2007; Kumar et al., 2019).

Transdisciplinarity seeks to deal with more complicated and heterogeneous domains (Nowotny et al., 2001). This concept can be viewed as an integrated framework of defining and analyzing multiple aspects of human health and well-being through a systematic theoretical framework, thus transcending the narrow disciplinary worldview (Stokols et al., 2003).

In this research, *interdisciplinarity* was used because it could accurately describe the integration of relevant single-disciplinary knowledge, providing a more advanced viewpoint for solving a specific issue as emphasized in this research.

Interdisciplinary Understanding of Environmental Issues in Upper-secondary School Science

Boix and Duraisingh (2007) defined interdisciplinary understanding as "the capacity to incorporate knowledge and modes of thinking in two or more disciplines or established areas of expertise to generate a cognitive advancement—such as clarifying a sensation, solving a problem, or creating a product—in ways that would certainly have been difficult or unlikely through single disciplinary means" (p. 219). Based on the knowledge integration approach (Linn, 2006), Shen et al. (2014) conducted a conceptual framework of interdisciplinary understanding to consider three necessary cognitive processes in the integration: translation, transfer, and transformation. They found that students' beliefs are frequently scattered and come from various sources. They further suggested that students

https://doi.org/10.33225/jbse/21.20.811

connect various pieces of information to explain complicated events and solve complex problems.

In this research, *interdisciplinary understanding* is more than just the "intersection of different disciplines"; instead, it necessitates integration by learning interrelated scientific concepts and approaches beyond single-disciplinary constraints. Thus, in upper-secondary school science, interdisciplinary understanding of environmental issues refers to the capacity to integrate concepts and approaches beyond disciplinary constraints to explain the causes of environmental issues, explore the global impact of environmental issues, and propose measures to address environmental issues.

Assessment Associated with Interdisciplinary Understanding in Science Education

To date, there have been only a few assessment studies focusing on students' interdisciplinary understanding. For instance, Schaal et al. (2010) measured 9th-grade students' interdisciplinary understanding of thermodynamics in mammalian hibernation using computer-assisted concept maps. They assessed students' ability to relate concepts from biological and physical disciplines to each other. The authors clearly stated that they thought the concept maps have a high level of reliability, but they did not specify which index was used to measure the reliability. Similarly, Reiska et al. (2018) also used a concept map to assess upper-secondary school students' interdisciplinary understanding on the functioning of instant ice packs. Students were required to create concept maps using the computer software IHMC CmapTools. They compared variance in students' interdisciplinary understanding from different schools and grades by a numerical interdisciplinary quality index (IQI). However, there was no mention of the validation procedure for the concept map assessment in this research.

Shen et al. (2014) developed 25 items (16 multiple-choice questions and nine constructed-response questions) for measuring post-secondary school students' interdisciplinary understanding in osmosis. The assessment necessitated a comprehensive understanding of physics (e.g., pressure), chemistry (e.g., chemical solutions), and biology (e.g., semi-permeable membranes). Specifically, the Rasch partial credit model was used to validate the items' psychometric properties.

You et al. (2018) used the Interdisciplinary Scientific Assessment of the Carbon Cycle (ISACC), comprising 11 multiple-choice questions and eight constructed-response questions, to measure 44 upper-secondary school students and 410 post-secondary school students. Cronbach's alpha reliability for all items was.782 and only one item had unexpected psychometric statistics, showing moderate internal accuracy for the instrument.

Tripp et al. (2020) developed an essay assignment instrument called Interdisciplinary Science Rubric (IDSR) using a theoretically and empirically based method to assess post-secondary school students' interdisciplinary understanding. They analyzed students' and instructors' think-aloud to examine the construct validity evidence of IDSR. They further evaluated reliability based on inter-rater reliability ($\kappa = 0.67$). Their results showed that the IDSR is reliable and valid for measuring students' interdisciplinary understanding.

Taken together, the studies above make positive contributions to interdisciplinary understanding assessment. However, those studies mainly aimed at post-secondary and secondary school students and only focused on explaining interdisciplinary scientific phenomena by multidisciplinary content knowledge. Meanwhile, some existing assessment instruments (e.g., concept maps and essay assignments) have some limitations for evaluating large samples regarding the qualitative nature of the approaches (You et al., 2019). Hence, this research developed a reliable assessment instrument comprised of multiple-choice and constructed-response items that required students to interdisciplinarily analyze causes, explore effects, and propose solving measures to assess over 500 upper-secondary school students' interdisciplinary understanding.

Assessment of Student Understanding of Environmental Issues

For decades, environmental issues have been debated, such as air pollution and climate change, deforestation, species extinction, soil degradation, and overpopulation (Harper & Snowden, 2017). Researches on student understanding of environmental issues have mainly concentrated on single disciplines rather than interdisciplinarity. Students are assessed on their understanding of causes of climate change in geology (e.g., Chang & Pascua, 2016), the absorption of infrared radiation by gases in physics (e.g., Versprille et al., 2017), the composition of polluted air in chemistry (e.g., Boyes et al., 2004), the direct and indirect causes of species extinction in biology (e.g., Moyer-Horner et al., 2010). However, there are currently limited assessment instruments measuring students' interdisciplinary understanding of environmental issues.

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Research Purpose and Research Questions

The purpose of this research was twofold: first, to develop and validate an assessment tool for measuring upper-secondary school students' interdisciplinary understanding of environmental issues by applying the Rasch model to demonstrate psychometric properties of the instrument; second, to use Rasch analysis to determine item difficulty as a basis for using the cluster analysis to divide items into different groups and identify the participants' levels of interdisciplinary understanding.

Specifically, the following two questions guided this research:

1. What empirical evidence supports the reliability and validity of the instrument in assessing student interdisciplinary understanding of environmental issues?
2. What levels of interdisciplinary understanding of environmental issues can participants achieve?

Research Methodology

General Background

Little research has been done in assessing upper-secondary school students' interdisciplinary understanding in science. There is a need to be done to assess upper-secondary school students in interdisciplinary assessments. In this context, the interdisciplinary understanding instrument covering five typical environmental issues towards upper-secondary school students has been designed in the research.

This research was descriptive-quantitative in nature, in which upper-secondary school students' interdisciplinary understanding of environmental issues was measured, collected, and descriptively reported. The researchers did not interfere in the assessment process to enable students to answer all assessment items. The data were further analyzed with Rasch analysis and cluster analysis methods. The research was conducted among 11th-grade students attending upper-secondary school in Zhejiang Province, China, during the 2019-2020 academic year. The science teachers from the two schools were in charge of administering the test, which took about 30 minutes.

Sample

The sample was from two public upper-secondary schools in Zhejiang Province, China. Because of their current relationship with a university research team, the two schools were selected using the convenience sampling method. The two schools are endorsed as the provincial key upper-secondary schools by the educational evaluation agency of Zhejiang Province, implying the highest level of evaluation, with first-class school conditions, teachers, and management. Eleventh graders were chosen because by this grade, Chinese students have already completed all single-subject compulsory scientific courses, including biology, geography, physics, and chemistry. In other words, the same learning experiences of compulsory courses lay a common foundation for all 11th graders.

In the research, 523 eleventh grade students were randomly selected from the two upper-secondary schools mentioned above as the research sample. The sample consisted of 244 girls (46.7%) and 279 boys (53.3%) aged 16 - 17 years. Considering certainty in ethical consideration, the first author had the consent of the school administration and faculty. All participants were voluntary and anonymous. All students were informed of the purpose of the data collection and the right to leave the assessment at any time. Students were also assured that their results would not affect their grades or class standing in any way. The confidentiality and privacy of participants were respected and protected all the time.

Instrument and Procedures Development

Figure 2 presents the construct modeling design process (Wilson, 2005). In particular, four design phases have been taken to develop the instrument: (1) Construct Map; (2) Item Design; (3) Outcome Space; and (4) Measurement Model.

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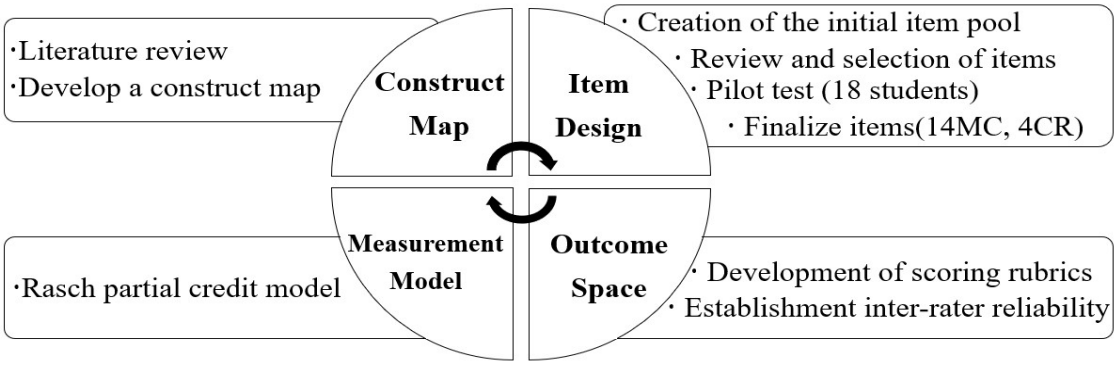
Figure 2
Overview of the Instrument Development Process



Definition of construct map. Instead of creating items, the first phase of construct modeling is to develop a construct map to improve construct validity (Wilson, 2005). The following operationalized concept of interdisciplinary understanding of environmental issues was used to create a construct map: students' performance in integrating concepts and approaches beyond disciplinary constraints to explain environmental issues or construct an argument about environmental issues. In reference to You's (2017) interdisciplinary understanding levels of carbon cycling, the construct map contained three levels depicting fundamental rules and growing sophistication along with the development process of interdisciplinary understanding of environmental issues (see Table 1).

Table 1
Construct Map of Interdisciplinary Understanding of Environmental Issues (adapted from You, 2017)

Interdisciplinary understanding level	Description
Level 1	Students hold potentially fragmented scientific ideas. They use some partially accurate scientific concepts and approaches, and their responses are from the perspective of a single discipline to explain the causes of environmental issues, explore the global impact of environmental issues, or propose measures to address environmental issues.
Level 2	Students present a purposeful aggregation of scientific ideas. They use some partially accurate scientific concepts and approaches from two or more necessary disciplinary perspectives to explain the causes of environmental issues, explore the global impact of environmental issues, or propose measures to address environmental issues.
Level 3	Students have a coherent conceptual scientific framework. They accurately use related and accurate scientific concepts and approaches to explain the causes of environmental issues, explore the global impact of environmental issues, or propose measures to address environmental issues to demonstrate a fully interdisciplinary understanding.

Creation of the initial item pool. The three tenets mentioned below were used to construct the first item pool for the interdisciplinary understanding assessment. First, a collection of items should evoke a variety of degrees of students' interdisciplinary understanding. Second, the contexts of items should be real-life environmental issues. Finally, given that this research is not designed to examine students' ability to recall knowledge but to select and organize the relevant knowledge, a certain number of clues and provide sufficient ample information as "scaffolding" should be provided.

The item was designed by a team of experts, including three science educators and two experts from various natural science fields. Specifically, the curriculum standards of all science disciplines for upper-secondary schools in mainland China (Ministry of Education, 2017a, 2017b, 2017c, 2017d) were reviewed to ensure that the subject matter covered in the assessment does not exceed the student's current knowledge. For example, the Curriculum Standard of Biology Subject and the Curriculum Standard of Geography Subject in mainland China have proposed a requirement of understanding the meaning of "human activities and nature" in upper-secondary school biology

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

and geography (Ministry of Education, 2017a, 2017c). Consequently, Item16 was developed to describe the impact of human activities on coral reefs, involving interdisciplinary connections related to carbon dioxide transition emissions. It included three discipline contents: food chain and photosynthesis for biology, ocean acidification for chemistry, and atmosphere interactions for geography. Among the 18 items, fourteen items were self-developed, and the others (Item 10, Item13, Item16, and 18) were from the You et al. (2018) research.

Review and selection of items. Additional four experts in science education, all the four experts with over 20 years of science teaching experience, were invited to review the initial item pool, including assessing each item according to whether the item measures environmental issues on interdisciplinarity and suggesting changes to these items. This step was helpful to identify items that should be eliminated or further revised.

Pilot test. A pilot test was conducted on 18 eleventh-graders from a school in Shanghai, China, using convenient sampling. The assessment was administered by a chemistry teacher at an out-of-school program. Following the pilot test, there was a semi-structured interview to gather feedback from students and debriefing regarding the assessment items' difficulty to determine whether phrases or sentences in the items were difficult to comprehend, which might cause response errors. According to these students' responses, the wording of the items was modified to make them more straightforward.

Field testing items. The revised instrument comprised 18 items, including 14 multiple-choice (MC) items (Item1-Item14) and four constructed-response (CR) items (Item15-Item18). The assessment contexts, item types, and discipline knowledge that may be tested in the items were presented in Table 2.

Table 2
Interdisciplinary Understanding Items of Environmental Issues

Contexts	Items	Disciplines
Air pollution and climate change	3(MC)	Chemistry, Geography
	5(MC)	Geography, Physics
	10(MC)	Biology, Geography
	13(MC)	Chemistry, Geography, Physics
	16(CR)	Biology, Chemistry, Geography
	18(CR)	Biology, Chemistry, Geography
Deforestation	1(MC)	Biology, Chemistry
	14(MC)	Biology, Chemistry, Geography
	15(CR)	Biology, Geography, Physics
Species extinction	11(MC)	Biology, Chemistry, Geography
	12(MC)	Biology, Geography
	17(CR)	Biology, Chemistry, Geography
Soil degradation	6(MC)	Biology, Chemistry, Geography
	7(MC)	Chemistry, Geography
	8(MC)	Biology, Chemistry, Geography
Overpopulation	2(MC)	Biology, Geography
	4(MC)	Biology, Geography
	9(MC)	Biology, Chemistry, Geography

Taking Item14 as an MC item example (shown in Figure 3) and Item17 as a CR item example (shown in Figure 4). Item14 was designed based on deforestation and contains biodiversity, the greenhouse effect, and soil erosion. It assessed the extent to which students identify the adverse effects of large-scale exploitation of tropical rainforests; Item17 was about the Lake Nakuru designed based on extinction and contained human activities, urbanization, and ecology.

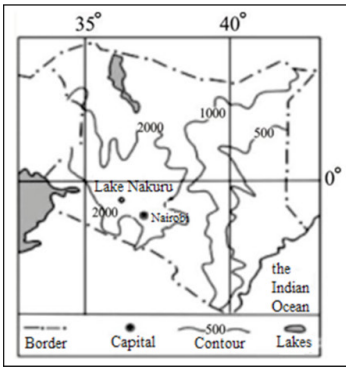
https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 3
Sample of Item 14(MC)

The Congo Basin in Africa is one of the three major distribution areas of tropical rainforests on earth, which is currently suffering from unprecedented destruction. In recent years, large-scale exploitation of tropical rainforests in the region has had the following adverse effects: ( )
① Decreasing biodiversity ② Increasing global greenhouse gas concentration and climate warming
③ Increasing groundwater level ④ Increasing soil erosion and sediment content of rivers
⑤ Increasing land salinization and desertification
A. ①②③ B. ②④⑤ C. ①②④ D. ①③⑤

Figure 4
Sample of Item17(CR)



Lake Nakuru and its surrounding area covers an area of about 200 square kilometers and is located at the bottom of the Great Rift Valley, a volcanic lake formed by violent changes in the earth's crust. The lava ash dispersed after the eruption flows into the lake by rain, and the lake has no outlet, so the saline material in the lake has been precipitated over the years, and the strong sunlight on the equator makes it suitable for the growth of algae and plankton, which are the staple food of flamingos. Flamingos prefer to inhabit the shallow waters of tropical saltwater lakes, marshes and lagoons, where their red feathers are used for craftwork. Lake Nakuru and its surrounding areas are home to more than 2 million flamingos, and is known as a "flamingo paradise". In recent years, however, with the growth of industry, agriculture, tourism and urbanization in the Lake Nakuru basin, the flamingo population has declined significantly. This figure shows the location of Lake Nakuru. Analyze how the amount of flamingo population decrease in Lake Nakuru and its surrounding area in recent years.

Development of scoring rubrics. The outcome space is related to how students' responses to an item will be graded (Wilson, 2005). The MC items were graded on a 0-1 scale, with 1 point awarded for each correct answer and 0 for three wrong responses. Rubrics for each CR item were developed to analyze students' responses based on the construct map of interdisciplinary understanding of environmental issues, which shows three hierarchical levels. The rubrics used a range of 0-5 for the four CR items. On the CR items, a score of 0 was given for inaccurately incorrect or irrelevant responses. A score of 1 was given for responses containing single discipline knowledge. A score of 5 was given for fully interdisciplinary responses. The remaining scores (2-4) differentiated in multiple-point structures, that is, the "intermediate clutter" (Gotwals & Songer, 2010), and were ranked by improving accuracy and completeness. By analyzing sample students' responses, these levels were generated. The first draft was professionally reviewed by four experts in science education, who also reviewed the initial item pool described above and revised it based on their feedback. Table 3 shows a representative rubric of Item 17, explaining each level and providing summaries of students' ideas.

Table 3
Sample Item with the Scoring Guide

Levels	Summaries of students' ideas	Patterns	Score
Level 0	Because Flamingos are important to our lives.	Incorrect/Off-topic/Restatement of the prompt	0
	The flamingo's genes have changed.		
Level 1	The ecology of the lake has deteriorated.	Unidisciplinary understanding	1
	Decrease in flamingos due to increased inflow to the lake.	Unidisciplinary understanding	1
	Industrial, agricultural and urban pollutants sink into the lake with surface runoff, and the lake's ecological environment deteriorates.	Unidisciplinary understanding	2
	Urbanization hardens the ground, and rainwater does not easily infiltrate during the rainy season, surface runoff increases, and the amount of water flowing into lakes increases.	Unidisciplinary understanding	2

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Levels	Summaries of students' ideas	Patterns	Score
Level 2	The increase in lake inflow and the decrease in lake water salinity have led to a decrease in the flamingo population.	Partially interdisciplinary understanding	3
	Increased water flows into the lake and deterioration of the lake ecosystem, resulting in fewer flamingos.	Partially interdisciplinary understanding	3
	Urbanization hardens the ground, and rainwater does not easily infiltrate during the rainy season, surface runoff increases, and the amount of water flowing into the lake increases, which is not conducive to algae growth and reduces food, resulting in fewer flamingos.	Partially interdisciplinary understanding	4
	Increased water flow into the lake, industrial, agricultural and urban pollutants sink into the lake with surface runoff, and the ecological environment of the lake deteriorates, resulting in fewer flamingos.	Partially interdisciplinary understanding	4
Level 3	Urbanization hardens the ground, and rainwater does not easily infiltrate during the rainy season, surface runoff increases, water flow into the lake increases, the salinity of the lake water decreases, which is not conducive to the growth of algae and food decreases. Industrial, agricultural and urban pollutants sink into the lake with surface runoff, the ecological environment of the lake deteriorates, resulting in fewer flamingos.	Fully interdisciplinary understanding	5
	Urbanization hardens the ground; rainwater does not easily infiltrate during the rainy season, surface runoff increases, the inflow to the lake increases, the salinity of the lake water decreases, which is not conducive to algae growth and food decreases; flamingo feathers are used as craft materials, leading to the artificial killing of flamingos.	Fully interdisciplinary understanding	5

Establishment of inter-rater reliability. Two research assistants (i.e., Master of Science in Education) with enough pertinent scientific knowledge took part in the independent scoring of each item. Where there were disparities, the raters reflected on feedback until an agreement was gotten on a rating. Inter-assessor reliability analysis was conducted using Kappa statistical information to figure out consistency among assessors. The inter-assessor reliability was Kappa = .93 ($p < .01$), suggesting excellent agreement (Landis & Koch, 1977).

Rasch model analysis approach. The final phase of the construct modeling is determining the measurement model. The data were analyzed using the partial credit Rasch model. The Rasch-type model serves as an IRT model in which student ability estimates and item difficulty estimates are independent of each other (Fischer & Molenaar, 2012), fixing some shortcomings of traditional score measures (Jiang et al., 2020). It also measured items and students in log units and provided item-person diagrams interrelated to two sub-structures (Bond & Fox, 2015).

Data Analysis

The partial credit Rasch model, via the WINSTEPS version 3.72 (Linacre, 2011), was applied for analysis to provide evidence for validity and reliability of measures based on the items (e.g., unidimensionality, items fit). Meanwhile, the cluster analysis called the "MD method" was developed by Marcoulides and Drezner (2000) to cluster patterns in detection data by dividing the observed measurements into different groups according to selected criteria. Rasch analysis was used to determine the difficulty of each item as a basis for using the MD method to identify the different levels of students' interdisciplinary understanding of environmental issues.

Research Results

Dimensionality

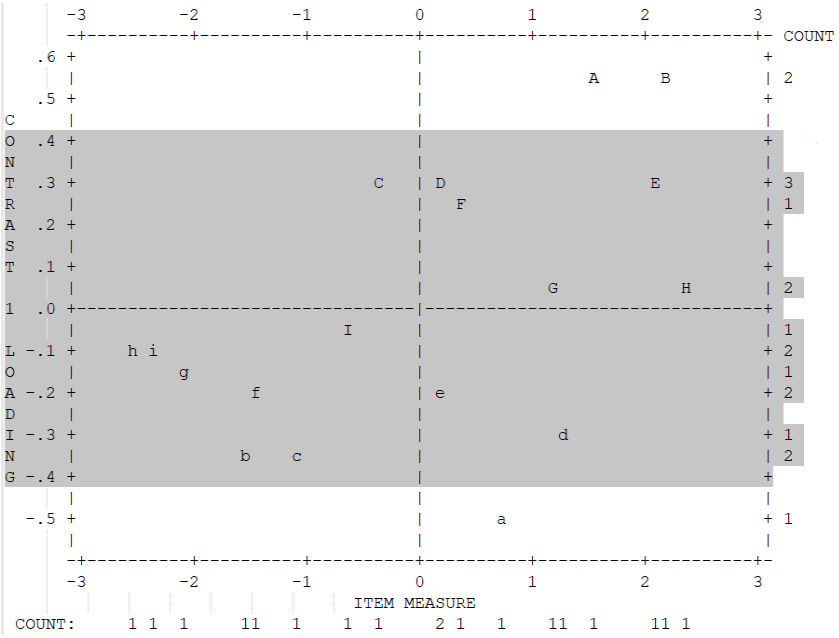
A dimensional analysis was carried out to evaluate whether these items could jointly measure a usual construct throughout disciplines. Principal component analysis (PCA) based upon Rasch residuals was performed to inspect the size of the range. Unidimensionality can be justified if the percentage of variance that cannot be explained caused by the potential secondary construct is less than 5% (Linacre, 2011). The results showed that the largest residual component (i.e., the first construct) had a proportion of unexplained variance of 4.6%, indicating that all 18

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

items were only measuring the construct of interdisciplinary understanding. A standardized residual contrast plot of the item loading was derived by PCA as shown in Figure 5. If the contrast loading of all items was between −0.4 to +0.4, the unidimensionality requirement of the assessment is satisfied (Luo et al., 2020). According to Figure 5, three items were beyond the range: Item12, Item14, and Item16, indicating that the items should be re-examined for analysis. Overall, the interdisciplinary understanding instrument met the unidimensional requirement, giving more evidence for the construct validity.

Figure 5
Standardized Residual Contrast Plot



Reliability

The fundamental issue of reliability in the sense of Rasch measurement is the accuracy or replicability of scores through repeated applications of the assessment instrument (Bond & Fox, 2007). Two reliability indices, reliability and separation, were investigated in this analysis. In general, a value of item separation higher than 3 and reliability higher than .9, and a value of person separation higher than 2 and reliability higher than .8 are considered adequate (Linacre, 2011). The item separation index was 13.35, and item reliability was around .99; the person separation index was 2.26, with the Cronbach's α value of .84. Overall, the high item reliability and separation indices showed that the variety of items could be differentiated; and the high person reliability and separation indicated that the instrument adequately separated student performance.

Validity: Fit Statistics and Wright Map

Item fit statistics. Item fit statistics provide evidence to distinguish the claims regarding the construct validity of the instrument's measurements, which shows the degree of match between actual item attributes and Rasch model predicted characteristics. Table 4 shows item difficulty ranging from -2.56 logits to 2.35 logits, and the Model standard errors for all items were below 1.0, ranging from 0.06 to 0.14. In addition, the point-measure correlation index (PTMEA) helps validate the relationship between the scores students gained on the particular item and their complete results (Linacre, 2011; Liu, 2010). The results showed that the values of PTMEA correlation of all items were positive, which was acceptable (Bond & Fox, 2015). The MNSQ values are virtually perfect when item's MNSQ falls within the variety of 0.5 to 1.5 (Liu, 2007, 2010). In this research, while the ZSTD values were not considered because of the high sample size (Liu, 2012; Smith et al., 2008). The problematic items Item 13, Item 5, Item 7, and

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Item 2 was with somewhat higher OUTFIT mean square, suggesting less accurate predictions of these items. Even though not all items meet all the criteria, the quality of the items is not affected (Laliyo et al., 2020). The item fit statistics showed that most items were not deviant, valid, and appropriate.

Table 4
Item Fit Statistics

Item	Measure	Model S.E.	Infit		Outfit		PTMEA CORR.
			MNSQ	ZSTD	MNSQ	ZSTD	
13	2.35	.14	.91	-1.0	2.32	4.5	.36
14	2.16	.14	.64	-5.0	.54	-2.8	.60
6	2.07	.13	.86	-1.8	.67	-1.9	.49
12	1.53	.12	.71	-5.1	.68	-2.5	.62
5	1.29	.11	1.35	5.5	1.76	5.2	.21
15	1.20	.07	.76	-4.3	.75	-4.6	.77
16	.72	.06	1.35	5.2	1.34	5.1	.57
17	.32	.06	.76	-4.4	.77	-4.2	.79
7	.21	.10	1.26	5.9	1.60	6.9	.29
18	.19	.06	.99	-.1	.99	-.1	.72
8	-.41	.10	.99	-.2	1.06	.8	.49
4	-.61	.10	.95	-1.1	1.08	1.0	.51
1	-1.07	.11	.84	-3.2	1.02	.2	.55
11	-1.42	.11	1.32	5.0	1.63	4.5	.23
10	-1.59	.12	.83	-3.0	1.11	.8	.52
9	-2.05	.13	.76	-3.5	.64	-2.4	.57
3	-2.34	.14	1.02	0.3	.85	-.7	.39
2	-2.56	.14	1.27	2.7	2.25	4.3	.15

Note: value all in logits.

Wright map: Item-person estimate map. The wright map displays both the distribution of student ability and item difficulty. Wright Map could also provide evidence of construct validity regarding the internal structure of items by examining whether the ordering and spacing of items are exhibited as expected (Boone & Staver, 2020). Figure 6 depicts the Wright (person-item) map. Each X represents a certain number of four students. Person at the top of the map have a high level of interdisciplinary understanding, while those at the bottom have a low level of interdisciplinary understanding. The items are arranged from top to bottom on the right side of the map, according to their high and low difficulty levels. Wright map shows that the items are allocated equally to the participants and covered the spectrum of student capacity estimates. The successful fit between the item concentration pattern and the student skill concentration pattern showed optimized measuring accuracy in designing the interdisciplinary understanding of environmental issues instrument (Juttner et al., 2013).

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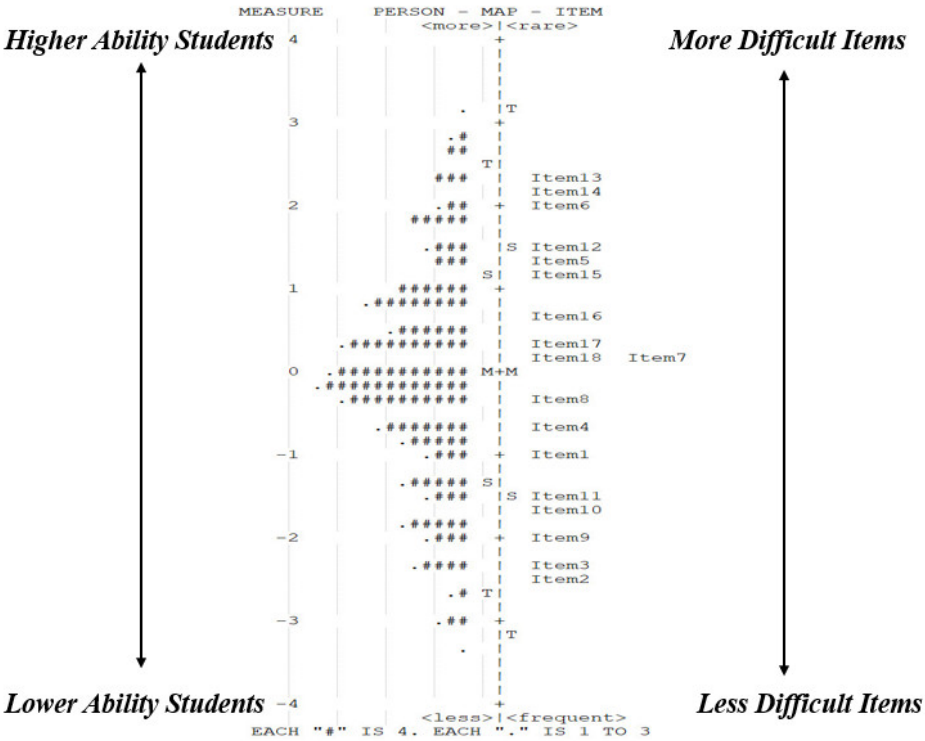
Figure 6
Wright Map (Person-item Map)



Levels Achieved by Eleventh Graders

The mean value of the person abilities was -0.08, a little lower than the average mean of item difficulties, which is 0 by default. This showed that the interdisciplinary understanding instrument was somewhat difficult for the sample. The item-person map in Figure 6 shows that the mean of the students' ability falls between the difficulty levels of Item8 and Item18.

The cluster analysis was used to define levels of interdisciplinary understanding of environmental issues. Using the MD method, the 18 items are grouped into three groups on the basis of item difficulty, as shown in Table 5.

Table 5
Three Levels of the Eighteen Items

Clusters	Rasch estimates	Items
1	…to -1.07	Item2 Item3 Item9 Item10 Item11 Item1
2	-0.61 to 0.72	Item4 Item8 Item18 Item7 Item17 Item16
3	1.20 to …	Item15 Item5 Item12 Item6 Item14 Item13

Based on the Rasch estimates, 523 eleventh-graders were classified into four groups ranging from Level 0 to Level 3. In the Rasch model, a person has a 50% chance of success on items with the same Rasch estimate on a logarithmic scale. According to the results, the greater the ability-difficulty difference in favor of student ability, the more likely students are to solve interdisciplinary environmental issues.

If a student's interdisciplinary understanding of environmental issues assessment is equal to or lower than the difficulty assessment of the items at Level 1, she or he is considered at Level 0 of interdisciplinary understanding of

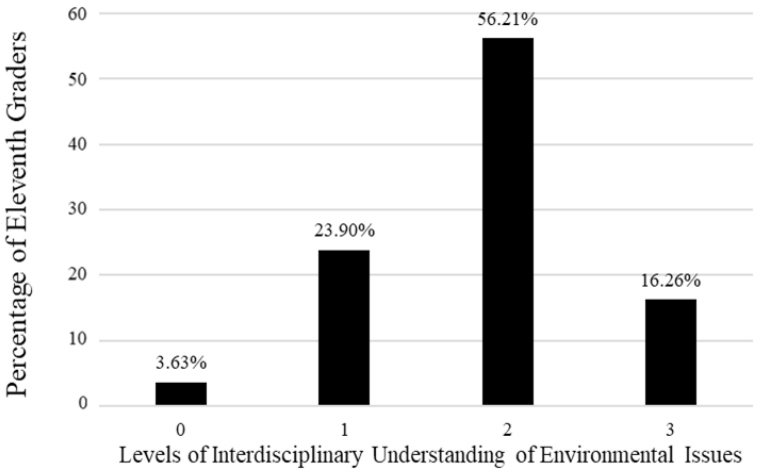
https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

environmental issues. Typically, a student is considered having achieved Level X of interdisciplinary understanding of environmental issues if her or his interdisciplinary understanding of environmental issues assessment exceeds the difficulty assessment of all things at Level X and is equal to or lower than the difficulty assessment of all items at Level X+1.

As illustrated in Figure 7, about 80 percent of 11th graders were classified as Level 2 (56.21 percent) or Level 1. (23.90 percent). Only 16.26 percent were able to answer all the interdisciplinary difficulties, while 3.63 percent fared poorly, even on Level 1 assignments.

Figure 7
Interdisciplinary Understanding of Environmental Issues of Sample by Level



Discussion

Along with recent work which addresses the "black hole" of assessment as interdisciplinary education (Mansilla, 2005), the focus of this research was to develop an assessment tool of upper-secondary school students' interdisciplinary understanding of environmental issues. First, an instrument consisting of 14 MC and 4 CR items was developed to measure interdisciplinary understanding of environmental issues through the construct-modeling framework (Wilson, 2005). Second, using Rasch analysis, the reliability and construct validity of the items were tested. Finally, this research investigated students' performance levels regarding the interdisciplinary understanding of environmental issues. The parts that follow go through our findings of the instrument's psychometric properties and students' performance on the field test.

Psychometric Properties of the Instrument (Research Question 1)

According to the dichotomous Rasch model and Rasch partial credit model application, the instrument has high reliability and item fit indices. The Rasch PCA verified the single construct of the interdisciplinary understanding of environmental issues instrument. The three items are a little out of range in PCA, which shows that they need to be revised or deleted. Nevertheless, there is not a distinct second trait.

The reliability of person measures is 0.84, which is more than the desired value of 0.70 (Nunnally et al., 1967). It indicated that the items might effectively distinguish between poor and high achievers. The average item difficulty is comparable to sample students' average ability.

The validity of measures of the interdisciplinary understanding of environmental issues instrument was confirmed with various approaches. Initially, the experts were asked to provide detailed comments on the content relevance of interdisciplinary items and any necessary adjustments to establish content validity. Second, the fit statistics (Table 4) revealed that the item difficulty and the estimation of students' ability were valid. Third, the Wright map (See Figure 6) offered evidence that items were distributed to the participants in a similar manner and

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covered the spectrum of student ability estimates. Because of the results described above, the construct validity is acceptable.

In general, the validity and reliability of interdisciplinary understanding of environmental issues items were justified for the preliminary phases of iterative development. Nevertheless, instrument development is a repetitive process (Liu, 2010); as reflected by the data, some items (Item12, Item14, Item16) need to be reconsidered. The difficulty estimations of Item18 and Item17 were very close; one of the two items need to be eliminated or could be reinvented. At once, a few items will be added to fill with gaps in the Wright map.

Eleventh Graders' Levels of Interdisciplinary Understanding of Environmental Issues (Research Question 2)

Cluster analysis suggested that more than half of eleventh graders could use some partially accurate scientific concepts and principles from two or more disciplinary perspectives to explain a specific environmental issue (level 2). This empirical finding identified in this research is unlike the result of You et al. (2018), which found that most upper-secondary school students are competent only at the lowest level required by interdisciplinary understanding. In their work, the small sample size of upper-secondary school students is a limitation, and the items are not very suitable for upper-secondary school students, which negatively affects the robustness of the obtained findings and provides an undue influence for outliers or severe observations.

The Chinese students' better performance on the interdisciplinary assessment in the research may be due to a variety of reasons. First possible explanation is that recent curriculum reforms may have had a positive impact on students' performance in the interdisciplinary understanding of environmental issues. At the end of 2017, the science curriculum standards for upper-secondary school were revised (Ministry of Education, 2017a, 2017b, 2017c, 2017d), which is competency-based curriculum reform to integrate interdisciplinary process in upper-secondary school education (The State Council of China [SCC], 2019). Second, Chinese students who performed better on the interdisciplinary items have probably benefited from interdisciplinary school-based learning. While all academic courses are separated all over China at the senior secondary stage, there is a growing interest in developing school-based curricula in both formal and informal education which are in the involvement of the integrative content (such as STEM curriculum, project-based learning courses, museum-based science learning), especially these trends occur mostly in cities situated in developed areas (Liang et al., 2017). Third, the Chinese students' excellent disciplinary performance may have affected this situation. Previous research has revealed a favorable relationship between interdisciplinary understanding and disciplinary knowledge (You, 2016; Zhang & Shen, 2015). It is increasingly recognized that Chinese students do well in science through the prism of international appraisal programs such as the PISA (OECD, 2010, 2013, 2016, 2019).

However, the participants lacked the necessary capacity to complete fully interdisciplinary tasks. Students' interdisciplinary understanding is limited because of their minimal interdisciplinary academic experience (Shen et al., 2014). Further improvements in interdisciplinary learning and teaching of science in upper-secondary school are necessary to prepare students to think and study interdisciplinarily to address these real-world challenges.

Conclusions and Implications

The lack of suitable interdisciplinary assessment instruments in science education, particularly for upper-secondary school students, necessitates developing new tools to overcome current hurdles. This research advances the field by creating a robust instrument for capturing upper-secondary school students' interdisciplinary understanding of environmental issues. The topic of environmental issues is intrinsically interdisciplinary, allowing for the development of interdisciplinary items by combining ideas and knowledge from different science disciplines.

This research gives insight into the procedure of developing trustworthy and verified measurement tools for students, scholars, and evaluation developers. Based upon Wilson's Construct Modeling framework, the interdisciplinary understanding instrument was developed and validated to assess upper-secondary school students' interdisciplinary understanding of environmental issues through a more systematic process. Developing a construct map, creating initial items and scoring rubrics, pilot testing, and modifying were all parts of the thorough development process.

The results can also provide two sets of insights into assessing upper-secondary school students' interdisciplinary understanding of environmental issues. First, the Rasch analysis demonstrated that measures from the interdisciplinary understanding assessment instrument are valid and reliable, making them suitable for interdisciplinary

https://doi.org/10.33225/jbse/21.20.811

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

understanding measurement. Science educators and other researchers can easily adapt and apply the instrument to diagnose and analyze upper-secondary school students' interdisciplinary understanding of environmental issues. Second, the cluster analysis indicated that most subjects achieved partial interdisciplinary understanding, although they were still far from fully interdisciplinary understanding. In order to foster advanced interdisciplinary thinking, a joint effort of educators and teachers is needed. Specifically, recognizing the value of interdisciplinarity in science curriculum policies, developing interdisciplinary school-based learning, and improving student achievement in science can provide a strong impetus to the development of interdisciplinary understanding. Beyond this, providing more opportunities for students to partake in interdisciplinary scientific activities could stimulate interdisciplinary connected learning.

Despite the fact that this research expanded the measuring of interdisciplinary understanding to upper-secondary school students, it still has two drawbacks. Firstly, eleventh graders from two excellent schools in Zhejiang Province were only picked owing to the constrained circumstances, so that the variation of student populations may not be wide enough. A future research path might be to expand the sample size more randomly from different schools and grades. Secondly, the Rasch analysis and cluster analysis do not propose any mechanism; factors influencing students' interdisciplinary understanding certainly require additional investigation. In the future, mixed-method research will be needed to confirm factors impacting students' interdisciplinary understanding and examine these factors' potential impact.

Acknowledgements

The research is supported by the following two projects: Shanghai Pujiang Program (No. 2020PJC032) and the MOE Key Research Institute of Humanities and Social Sciences (No. 17JJD880007).

Declaration of Interest

Authors declare no competing interest.

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Received: *June 22, 2021* Accepted: *September 25, 2021*

Cite as: Lan, Y., Chi, S., & Wang, Z. (2021). Assessing upper-secondary school students' interdisciplinary understanding of environmental issues. *Journal of Baltic Science Education*, *20*(5), 811-826. https://doi.org/10.33225/jbse/21.20.811

Yu Lan MEd, (Science Education), PhD Candidate, College of Teacher Education, Faculty of Education, East China Normal University, Shanghai, China.
E-mail: 641486344@qq.com
ORCID: https://orcid.org/0000-0002-7691-5309

Shaohui Chi *(Corresponding author)* PhD, Associate Professor, College of Teacher Education, Faculty of Education, East China Normal University, Shanghai, China.
E-mail: charlcy@163.com
ORCID: https://orcid.org/0000-0002-1261-7951

Zuhao Wang PhD, Professor, College of Teacher Education, Faculty of Education, East China Normal University, Shanghai, China.
E-mail: wangzuhao@126.com
ORCID: https://orcid.org/0000-0002-2967-8232

https://doi.org/10.33225/jbse/21.20.811