Iranian Journal of Comparative Education, 2025, 8(4), 3835-3850
Research Article DOI: 10.22034/IJCE.2025.479055.1606 http://journal.cesir.ir

A Comparative Study of Selected Features of the Primary School Curriculum in Iran, Singapore, Finland, and the United States Based on TIMSS Data, with an Emphasis on the Earth Sciences Component

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ARTICLE INFO

Received: 17 September 2024
Revised: 28 February 2025
Accepted: 10 March 2025
Online: 10 December 2025

ABSTRACT

This study aims to conduct a comparative analysis of key characteristics of the educational systems of Iran, the United States, Finland, and Singapore using data from the 2019 Trends in International Mathematics and Science Study in science education. Except for Iran, the countries were selected based on their high rankings in the TIMSS assessment. First, the relevant data were extracted, and several curriculum features—such as assessment methods, instructional content, and Earth science topics—were examined. The data were analyzed through clustering techniques to identify the structural similarities and differences among the educational systems. The findings indicate that the science curriculum in Iran, Finland, and Singapore is centrally administered, while in the United States, curriculum decisions are made at the state level. Regarding assessment practices, Singapore employs strict standards that promote deeper learning, whereas evaluation methods in Iran, Finland, and the United States are more flexible. However, Iran's system emphasizes rote memorization, while those of Singapore, Finland, and the United States prioritize critical thinking. Considering the diverse and reasoning-oriented nature of the TIMSS questions, this difference may explain Iran's relatively lower performance compared to the other three countries. Furthermore, the Earth science content in Finland and Singapore shows considerable similarity, whereas Iran's content shares more commonalities with that of the United States.

KEYWORDS

Assessment
Curriculum
Earth Science
Primary Education
TIMSS

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1. Introduction

The educational system of every country represents one of the most fundamental institutions with which societies around the world are directly engaged, as it plays a crucial role in the development of individuals and the overall progress of society. Sociologists argue that the presence of an efficient educational system constitutes the most essential pillar in building a successful society. Accordingly, education is recognized as one of the key instruments for achieving the social, cultural, and economic goals of modern societies (Arizi Samani et al., 2012; Ahadian & Aghazadeh, 2013; Bazobandi & Amani Tehrani, 2014).

An effective educational system provides a structure through which the learning process occurs purposefully and systematically in alignment with the objectives of society. Understanding learning and the factors influencing it is made possible through the application of educational theories. These theories offer scientific frameworks, principles, and foundations for designing, implementing, and evaluating teaching and learning practices (Strong et al., 2004; Gunderman, 2006). Various types of such theories—such as constructivism, behaviorism, and cognitivism—have been widely used in educational research. Educational theories thus provide the conceptual foundation for understanding learning processes and for designing instructional programs. They help teachers adopt appropriate methods for facilitating teaching and learning based on psychological and social principles (O'Donnell et al., 2024). Teaching and learning methods serve as the practical tools for implementing educational theories. Without theoretical underpinnings, teaching practices cannot be purposeful or effective. The interrelation between theory and practice enables teachers to enhance learning and to design instruction that meets the diverse needs and abilities of students. Teaching and learning methods can generally be categorized into five main strategies: exploratory, transmissive, procedural, interactive, and integrated (Shahratash et al., 2008).

Among these, the exploratory approach allows learners to discover answers independently and emphasizes active engagement with materials and resources. The transmissive approach, in contrast, involves providing students with information directly, with limited learner participation in the process. The procedural approach highlights the learner’s active participation and focuses on developing skills such as observation, communication, and classification. The interactive approach represents a combination of elements from the previous models, in which teachers actively explore students’ prior understanding and encourage them to ask scientific questions, thereby fostering a more inquiry-based learning environment. These multiple approaches to teaching and learning in science education raise an important question: Which of these instructional approaches can lead to a higher level of learning among students in science classes? (Seif, 2014; Soleimani & Seyed Hatami, 2016; Rakhshani Morad, 2017).

For the successful implementation of teaching and learning strategies, it is essential to consider the key dimensions and components of science education—namely the cognitive (understanding scientific concepts), skills-based (developing practical competencies), attitudinal (fostering positive attitudes toward science), and social (enhancing group interaction) dimensions. Attention to these components, combined with the use of appropriate assessment tools and educational technologies, contributes to improving the quality of learning and promoting students' comprehensive development in science education (Strong et al., 2004; O'Donnell et al., 2024).

These dimensions and components reflect the multifaceted nature of science education that must be addressed in curriculum design, implementation, and evaluation. They influence every aspect of learning—from knowledge acquisition and skill development to attitudes and social interaction. The cognitive dimension focuses on understanding scientific principles and enhancing critical thinking. The skills-based dimension emphasizes the development of practical and laboratory abilities, enabling students to apply their scientific knowledge to solve real-world problems. The attitudinal dimension aims to cultivate curiosity, motivation, and a positive disposition toward science and scientific inquiry. Finally, the social dimension promotes group interaction and collaborative learning, strengthening students' communication and teamwork skills (Strong et al., 2004; O'Donnell et al., 2024).

In addition, science education encompasses several other essential components that play a significant role in curriculum planning and implementation. Educational objectives define the intended learning outcomes and guide the overall direction of instruction. Content refers to the topics and subjects that must be designed in accordance with students' developmental levels and educational needs. Teaching methods, such as problem-based learning or inquiry-based instruction, serve as tools for knowledge transfer and skills enhancement. Assessment, as a means of measuring learning progress, is of critical importance and may include tests, projects, or practical evaluations. Finally, educational technology—through the use of modern tools such as instructional software and virtual laboratories—enhances learning processes and increases the attractiveness and engagement of science education (Wang et al., 2023; O'Donnell et al., 2024). Assessment methods in Finland, for instance, are highly diverse and place strong emphasis on qualitative and descriptive evaluation. Written examinations are rarely conducted; instead, students are assessed primarily through classroom activities, projects, and continuous observation. In Finland, feedback is provided primarily in qualitative and descriptive forms, and numeric grades are rarely used. Such feedback typically includes teachers' comments on students' progress and learning needs. The main purpose of assessment in Finland is to support students' individual growth and development, rather than to promote competition or ranking (Finnish National Agency for Education, 2021).

In contrast, assessment methods in Singapore are based on a comprehensive and continuous evaluation system, which includes written examinations, practical tests, group and individual projects, and ongoing assessments. In addition, national examinations such as the Primary School Leaving Examination (PSLE) are administered at the end of primary education to evaluate students' competencies. Singapore's system places emphasis not only on the acquisition of knowledge but also on the development of practical skills and critical thinking abilities (Ministry of Education, Singapore, 2023; OECD, 2021).

In the TIMSS (Trends in International Mathematics and Science Study), the number of participating schools from each country depends on several factors such as student population, educational structure, and sampling methodology. Typically, each country is required to provide a representative sample of schools and students from both the fourth and eighth grades. The exact number of participating schools usually ranges between 150 and 300 per country. Within each school, one or more classes are randomly selected to take part in the assessment. The TIMSS questionnaires include a series of items designed to collect background information on a variety of educational and non-educational factors. In addition to the mathematics and science achievement tests, these questionnaires are completed by students, teachers, school principals, and parents to gather comprehensive contextual data. The questionnaires are developed by the TIMSS & PIRLS International Study Center, located at Boston College in the United States, under the supervision of the International Association for the Evaluation of Educational Achievement (IEA) (TIMSS & PIRLS International Study Center, 2015). The design of these instruments involves the collaboration of researchers, educational experts, and assessment specialists from multiple countries.

2. Problem Statement

Science education, both in Iran and globally, faces numerous challenges that negatively impact its quality and effectiveness. These challenges include insufficient educational resources, ineffective teaching methods, limited attention to students' individual needs, and a lack of infrastructure for laboratories and practical activities (Elliniadou et al., 2024; Leijon et al., 2022; Osborne, 2013; Khademi et al., 2024; Khashman & Soltannezhad, 2022; Javidi et al., 2021).

One major issue is the lack of up-to-date instructional materials and the limited use of multimedia and digital learning resources (Elliniadou et al., 2024; Roche et al., 2020; Salehinejad et al., 2017; Zarabian, 2018; Rezban et al., 2018). Another significant challenge lies in traditional, teacher-centered methods of instruction, which continue to dominate many classrooms (Ghorbani et al., 2019). In such environments, teaching often emphasizes rote memorization rather than the development of critical and creative thinking skills, leaving students with little opportunity to deeply understand scientific concepts or apply them to real-life contexts. Consequently, the use of modern, student-centered instructional methods has become essential (Bazoobandi et al., 2023; Attaran et al., 2016; Rahimi Mand et al., 2020).

In addition, the lack of educational infrastructure, particularly laboratories and scientific equipment, is a critical issue in many Iranian schools (Barahoei, 2022). Without adequate facilities, students are deprived of the practical experiences necessary for meaningful science learning. Science education without hands-on and experimental activities is inherently incomplete and cannot lead to deep conceptual understanding (Hofstein & Lunetta, 2004; Trnová & Trna, 2011). To improve the current state of science education, fundamental reforms in teaching methods, updating instructional resources, and investment in educational infrastructure are urgently needed. Addressing these challenges and developing appropriate strategies for improvement are vital given the growing importance of science education in today's world (Kremer et al., 2013; Elliniadou et al., 2024; Leijon et al., 2022; Osborne, 2013; Khademi et al., 2024; Khashman & Soltannezhad, 2022; Javidi et al., 2021).

Studies by McGill et al. (2020) have shown that educational systems emphasizing critical thinking—such as those of Singapore and Finland—tend to perform better in international assessments like TIMSS, whereas memory-based systems, such as Iran's, face difficulties in adapting to such cognitively demanding tests. Iran has participated in the TIMSS assessment since 1993, most recently in 2023, and has consistently achieved low and unsatisfactory rankings. Therefore, the present study seeks to identify the underlying causes of this persistent underperformance and to analyze the factors contributing to the gap between Iran and the higher-performing countries of Singapore, Finland, and the United States.

3. Research Method

The research method employed in this study is based on the analysis of educational data from the systems of Iran, the United States, Finland, and Singapore, using the results of the 2019 Trends in International Mathematics and Science Study (TIMSS) in the field of science education, with a particular emphasis on the Earth sciences component. The selection strategy for these countries was determined according to their levels of achievement in the TIMSS 2019 results, focusing specifically on the science domain related to Earth sciences. The data collection process involved the examination of TIMSS 2019 international reports, as well as an analysis of students' performance in science and the educational characteristics of the selected countries. According to the official TIMSS 2019 Science Framework, the science assessment items were primarily designed to measure problem-solving ability, scientific reasoning, and data analysis. In contrast, the analysis of domestic Iranian examinations (e.g., national final exams) revealed that the majority of questions emphasize rote recall and reproduction of information rather than analytical or reasoning skills.

4. Findings

This study conducted a comparative analysis of elementary-level Earth science education across the selected countries, focusing on three main dimensions:

- the specific characteristics of the primary science curriculum,
- assessment methods, and
- the content structure of Earth science education.
- Characteristics of the Curriculum

a) Specific characteristics of the primary science curriculum

In this section, the curriculum data of the selected countries were analyzed using the TIMSS 2019 database. To process and identify structural relationships among educational systems, hierarchical cluster analysis was applied (Table 1).

Table 1. Curriculum Information in Science Education of the Selected Countries

Question Code	**Curriculum Feature**	**Finland**	**Iran**	**Singapore**	**USA**
a	Existence of a national science curriculum	Centralized	Centralized	Centralized	Decentralized
b	Process of updating the science curriculum	Decentralized	Centralized	Centralized	Centralized
c	Determination of allocated time for science education	Centralized	Centralized	Centralized	Decentralized
d	Establishment of policies and regulations	Centralized	Decentralized	Centralized	Centralized

	on the use of digital technologies in science instruction				

Source: Extracted and adapted from TIMSS 2019 database.

According to the TIMSS data on curriculum structures, Iran, Finland, and Singapore have adopted centralized systems for science education at the elementary level, whereas in the United States, the curriculum is decentralized, with each state determining its own educational standards and content. Curriculum updating and alignment with new scientific and technological developments, another aspect examined in the TIMSS questionnaires, is observed in all countries except Finland, where revisions are implemented locally and not mandated through a national centralized mechanism. The allocation of dedicated instructional time for science education exists in Iran, Finland, and Singapore, while in the United States, this decision is left to individual teachers, who have the flexibility to determine how much time to devote to science instruction based on their professional judgment and classroom context. Another key feature concerns the existence of formal policies regarding the integration of digital technologies, such as computers, tablets, and calculators, into science education. Such policies are in place in all countries except Iran, where the use of educational technology in science instruction remains largely unregulated and inconsistent.

A hierarchical cluster diagram was developed based on these curriculum characteristics (Figure 1). The clustering results suggest that the curricular features of Iran are broadly comparable to those of Finland, Singapore, and the United States, indicating no significant structural differences that could, by themselves, account for Iran's weaker performance in TIMSS. Consequently, it appears necessary to explore other curricular factors, such as assessment practices and content design, to identify the underlying reasons for Iran's relative underachievement compared to the high-performing countries.

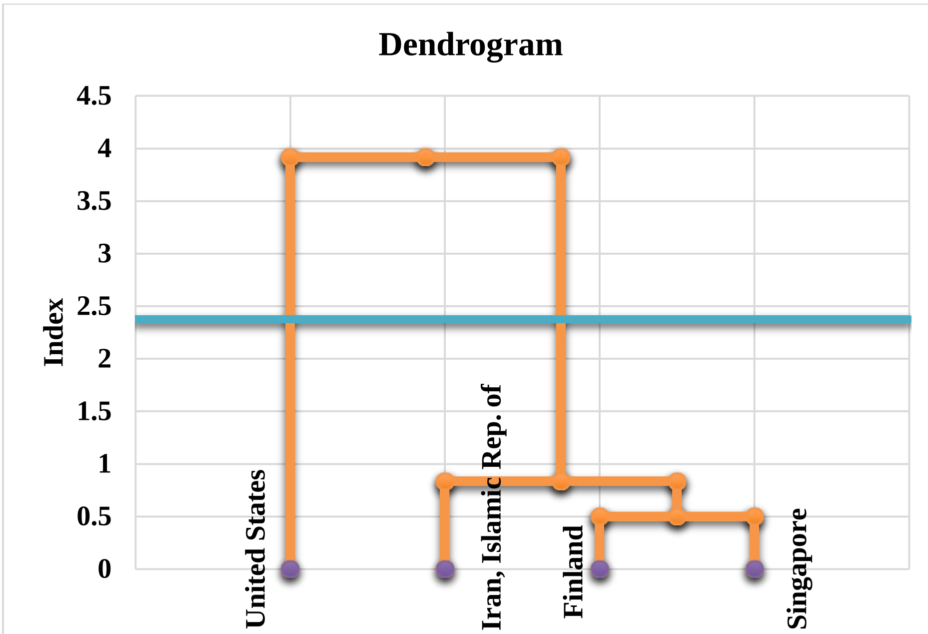

Figure 1. Cluster Diagram of General Curriculum Information in Science Education among the Selected Countries

(b) Evaluation Methods

Another critical aspect of curriculum design concerns the methods of assessment and evaluation. Based on the TIMSS framework, five main types of evaluation are used across educational systems: inspector visits, research programs, school self-evaluation, national or regional examinations, and other forms of review. The goal of these evaluations is to examine how science curricula are implemented and to assess their effectiveness in improving learning outcomes. Inspector visits involve direct observations conducted by curriculum supervisors or educational inspectors. Their purpose is to evaluate teaching practices, the use of instructional resources, adherence to curriculum standards, and the quality of student engagement with learning materials. Research programs consist of systematic investigations aimed at assessing the impact and effectiveness of the science curriculum. Such studies are typically carried out by universities, research institutions, or governmental agencies. Their objectives include identifying the strengths and weaknesses of the curriculum, analyzing its alignment with students' learning needs, exploring the relationship between curricular content and student performance on national or international assessments (such as TIMSS), and evaluating how curriculum reforms affect the quality of learning.

School self-evaluation refers to internal assessments conducted by schools, teachers, or academic teams to identify implementation challenges and improve curriculum quality through performance analysis and reflective practice. National or regional examinations are standardized tests administered at large scales to assess students' knowledge and skills in science. Their purpose is to determine the degree to which learning outcomes align with curriculum objectives and to enable cross-regional comparisons of student performance. The relevant information is summarized in Table 2 below.

Table 2. Evaluation Methods in Science Education across the Selected Countries

Question Code	How is the implementation of the Earth Science curriculum evaluated?	Iran	Singapore	USA	Finland
a	Inspector visits	No	No	Yes	No
b	Research programs	Yes	No	Yes	Yes
c	School self-evaluation	No	Yes	Yes	Yes
d	National or regional examinations	Yes	Yes	Yes	Yes
e	Other forms of evaluation	Yes	Yes	No	No

Source: Extracted and adapted from TIMSS 2019 database.

The cluster analysis of assessment methods (Figure 2) reveals two primary groupings among the selected countries:

- Iran and Singapore, which share similar evaluation structures, and
- the United States and Finland, which also exhibit strong similarities.

Singapore's assessment system is distinguished by its rigorous and comprehensive standards, incorporating frequent reviews and multiple assessment forms. This ongoing evaluation process helps students revisit and consolidate learning, which may explain Singapore's consistently high performance in TIMSS across all assessment cycles. In contrast, Iran lacks a school self-evaluation system, which is present in all three of the other countries. This absence represents a critical gap in Iran's educational evaluation framework, as school self-evaluation serves as an essential mechanism for continuous improvement, reflective teaching practices, and localized curriculum enhancement. Consequently, one of the key factors contributing to Iran's weaker performance in TIMSS may be the absence of systematic internal evaluation processes within schools.

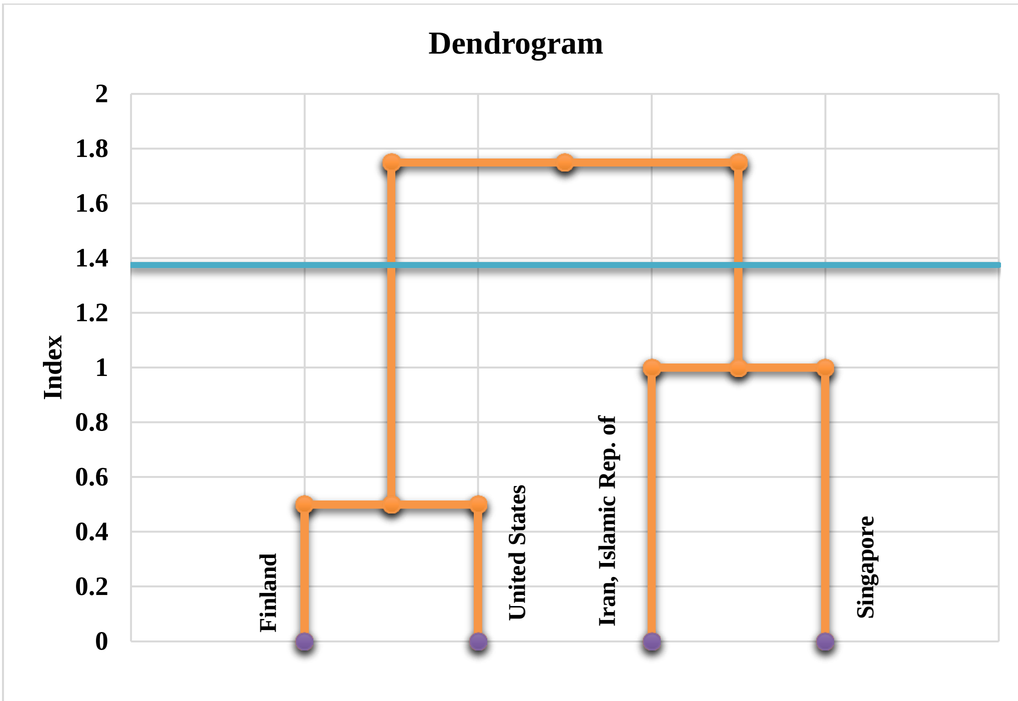

Figure 2. Cluster Diagram of Assessment Methods in Science Education among the Selected Countries

(c) Educational Content and Earth Science Topics

After analyzing the curriculum structure and assessment methods, the next step was to examine the content and topics of Earth science included in the elementary science curriculum of the selected countries. Based on the data published in TIMSS 2019, the following table (Table 3) was compiled. This table specifies, according to each country's national curriculum, the proportion of Grade 4 students expected to have been taught each Earth science topic by the end of the fourth grade. Each question corresponds to a specific subtopic that should be covered within the science curriculum.

Table 3. Earth Science Topics in the Elementary Science Curriculum of the Selected Countries

Question Code	Topic	Finland	Iran	Singapore	USA
a	Physical structure of the Earth's surface (land and water distribution, freshwater and saltwater resources)	3	1	3	1
b	Earth resources used in daily life (water, wind, soil, forests, natural gas, minerals)	3	1	3	1
c	Changes on the Earth's surface over time (mountain formation, weathering, erosion)	3	3	3	1
d	Fossils and what they reveal about the Earth's past conditions	3	3	3	1
e	Weather and climate (daily, seasonal, and spatial variations vs. long-term trends)	3	1	3	1
f	Solar system objects (Sun, Earth, Moon, and other planets) and their movements	3	1	3	1
g	Earth's motion and related observable patterns (day and night, seasons)	1	1	3	1

Note:
1 = All students are expected to be taught the topic
2 = Only higher-achieving students are expected to learn it
3 = The topic is not included up to Grade 4 in the national curriculum

According to the TIMSS questionnaire data, the content of science curricula varies significantly across countries due to differences in educational goals, system structures, and cultural and socio-economic contexts. These variations reflect how each country defines the purpose and scope of science education. For example, industrialized nations tend to emphasize the development of advanced scientific and technological competencies to maintain competitiveness in the global economy, while developing countries often prioritize basic scientific literacy aimed at addressing local needs and promoting everyday problem-solving. Cultural values also play a major role in shaping curriculum content. In some contexts, environmental science and scientific ethics receive greater emphasis, whereas in others, the focus may be on technology and innovation. The structure of the educational system—particularly in terms of duration and the degree of centralization—further influences curricular depth and focus. Differences in allocated instructional time for science per week or year directly affect the extent to which topics such as Earth science are explored. In centralized systems (e.g., Iran), the curriculum is designed and standardized nationally, which ensures consistency but may reduce flexibility and local adaptation. Conversely, in decentralized systems (e.g., the United States), states or regions have the authority to design their own science programs, resulting in variability in topic selection, sequencing, and depth of instruction. These contextual differences explain the diversity observed in Table 3 and highlight how curriculum policy, educational philosophy, and societal priorities collectively shape the way Earth science is taught at the elementary level across countries.

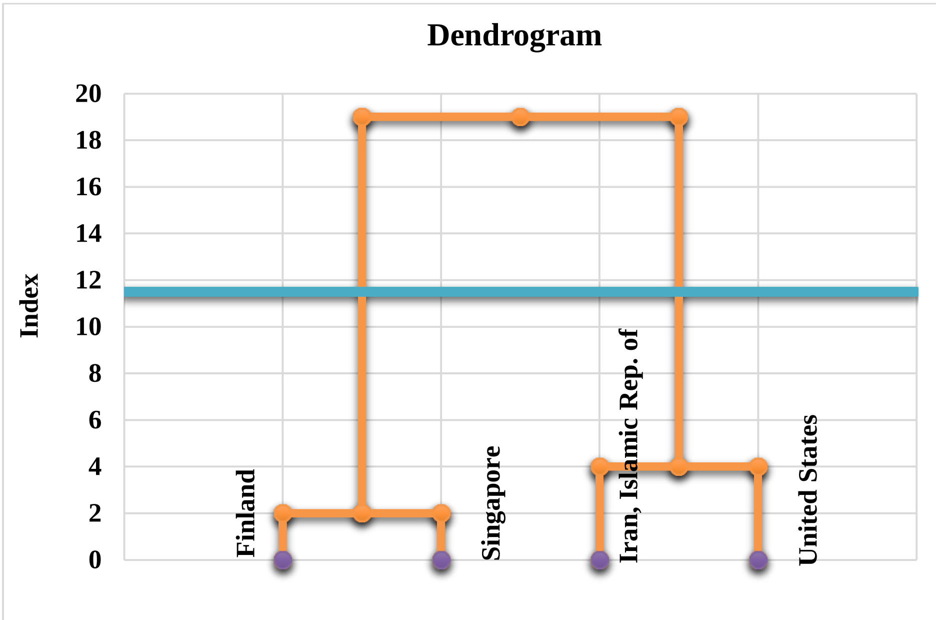

Figure 3. Cluster Diagram of Earth Science Topics in the Selected Countries

According to the cluster diagram in Figure 3, the selected countries are classified based on their Earth science curricula. This diagram schematically illustrates the similarities and differences in the content of Earth science education among these countries. Based on the results, it is observed that Singapore does not include any geology-related content in its curriculum up to the fourth grade, while Finland only covers the topic of Earth's motion and related observable patterns (day and night, seasons). Therefore, Finland and Singapore are grouped together in one cluster, as both provide a limited amount of Earth science content during the first four years of elementary education. On the other hand, the United States and Iran are grouped into another cluster. These two countries, up to the fourth grade, address several Earth science topics such as the physical structure of the Earth's surface, Earth's resources, solar system objects, weather and climate, and Earth's motion and related observable patterns (day and night, seasons). However, the United States covers more advanced topics than Iran, including changes in the Earth's surface over time and fossils and the Earth's past conditions.

5. Conclusion

In this study, Earth science education during the first four years of primary school in Iran, the United States, Finland, and Singapore was examined in three main areas: specific curriculum features, assessment methods, and Earth science content, based on data from TIMSS 2019. According to the findings, in terms of curriculum structure, the selected countries are dynamic and active and share many similarities, differing only slightly in how their curricula are implemented. Regarding assessment methods, the selected countries have adopted different approaches, which reflect notable differences in their educational philosophies and perspectives. In Singapore, assessment methods are characterized by strict standards and a comprehensive and continuous evaluation system, including written exams, practical tests, group and individual projects, and ongoing assessments. Moreover, national examinations are conducted at the end of the primary cycle to assess students' competencies. Therefore, the main reason Singapore consistently achieves better TIMSS results than the other three countries lies in its strong and continuous assessment system. In contrast, Iran lacks a school self-evaluation process, which exists in the other three countries. Consequently, one of the reasons for Iran's weaker performance in TIMSS may be the absence of internal school evaluation. In Finland, assessment methods are highly diverse and focus primarily on qualitative and descriptive evaluation. Written examinations are rarely administered, and assessment is mainly based on projects and classroom activities. Feedback is provided in a qualitative and descriptive manner, and numerical grades are rarely used. Such feedback typically includes teachers' comments on students' progress and individual needs.

Assessment methods in Iran and the United States include a variety of approaches, such as written examinations, classroom projects, performance-based assessments, and continuous evaluations during the term, including short quizzes, classroom activities, and homework assignments. In addition, standardized tests are conducted at specific grade levels. However, assessment in Iran is more memory-oriented, while in the other three countries, it is thinking- and reasoning-oriented. Considering the diverse and reasoning-based nature of TIMSS questions, one of the main reasons for Iran's lower performance compared to the other countries is this difference in assessment philosophy. With regard to Earth science content, in Finland, science education in grades 1 to 4 is taught as an integrated subject under the title Environmental and Natural Studies, which includes biology, geology, physics, chemistry, and health education. In Singapore, the science curriculum is designed to develop scientific literacy and research skills among students and is organized around three main themes: Diversity, Cycles, and Systems. In the United States, science education is organized around three dimensions—disciplinary core ideas, scientific and engineering practices, and crosscutting concepts—as outlined in the Next Generation Science Standards (NGSS), which provide a framework for science education nationwide. In Iran, the science curriculum is developed by the Ministry of Education and is uniformly implemented across all schools in the country. The content includes fundamental topics in geology, biology, physics, and chemistry, with an emphasis on theoretical concepts and foundational knowledge. Instruction is primarily lecture-based, using textbooks as the main resource. Although laboratory and practical activities are included, they are less emphasized than in educational systems such as those of the United States or Singapore.

Based on the findings of this study, in order to improve Iran's performance in future TIMSS assessments, it is recommended that educational policymakers, curriculum developers, and science teachers reconsider current assessment and teaching practices. Specifically, it is suggested that assessment methods be revised to more closely align with the TIMSS evaluation framework, incorporating a greater number of higher-order, cross-disciplinary (meta-cognitive) questions that assess reasoning and problem-solving skills rather than rote memorization. Furthermore, in the area of instructional methods, teachers are encouraged to move away from memory-based teaching and to adopt thinking-oriented and inquiry-based approaches that foster students' creativity, curiosity, and scientific reasoning. Such reforms would contribute not only to improving Iran's standing in international assessments but also to promoting deeper and more meaningful science learning among students.

Acknowledgment

The authors would like to express their sincere gratitude to the Research and Technology Council of Farhangian University for providing financial support for this study under the Postdoctoral Research Project No. 50000/17337/60.

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