International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 1, February 2025, pp. 648~658
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i1.30225

Determination of pedagogical principles for building functional science literacy of school children

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Article Info

Article history:

Received Feb 11, 2024
Revised Oct 12, 2024
Accepted Nov 15, 2024

Keywords:

Education
Pedagogy
PISA
School children
Science literacy

ABSTRACT

In this study, it was aimed to determine the pedagogical principles for building functional science literacy of school children in line with the Program for International Student Assessment (PISA) by examining the performing countries in PISA. The statistical results of the PISA results reports of China, Singapore, Hong Kong and Estonia were compared with the results of Kazakhstan. It was concluded that students in the top-ranked countries actively participate in scientific activities, enjoy practicing scientific activities, exhibit high-level cognitive skills, test and monitor the results of scientific research, and compete in national and international activities. The economic status of the family, learning environment, discipline, school equipment, and the number of teachers in the school are among the factors affecting children's science literacy. Teachers' continuous participation in in-service trainings, keeping their motivation at a high level, choosing different teaching methods, encouraging students to conduct research and activating high-level cognitive skills were considered among the most important reasons for good results in science PISA research. It is recommended that countries that want to rank higher in an international platform such as PISA should implement student-centered activities in their educational reforms and create educational environments where students can test their high-level skills.

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1. INTRODUCTION

In today's rapidly evolving world, the importance of science literacy among school children cannot be overstated [1]–[4]. Proficiency in the natural sciences not only equips young minds with basic knowledge, but also nurtures the critical thinking and problem-solving skills needed to tackle complex global challenges [5], [6]. International assessments such as the Program for International Student Assessment (PISA) have highlighted the need to improve science literacy and identify the most effective pedagogical methods [7]–[9].

The PISA study, conducted by the Organization for Economic Cooperation and Development (OECD), has become a global benchmark for assessing and comparing the science literacy of school-age students across countries [10], [11]. This comparison has revealed both strengths and weaknesses of science education systems around the world. One of the findings is that school-age children in many countries consistently underperform in science literacy [12], [13]. Identifying the reasons underlying this low performance is important in improving the quality of education in countries. Evaluating the PISA survey in this context, Robets identifies the prevailing political and intellectual views on scientific literacy and discusses whether science curricula should be designed to complement the subject matter that needs to be covered or emphasize life situations in which science plays a key role [14]. According to the result obtained in this discussion, the basis of scientific literacy is that the individual who has realized the necessary educational steps to have scientific knowledge is able to use this knowledge smoothly in the areas required by life [15]. Scientific literacy is more than just learning facts and numbers; it also entails having a thorough comprehension of scientific ideas, the capacity to assess information critically, and the ability to apply scientific knowledge to practical issues [16]. In an age where science and technology are the driving force in our societies, it is crucial to develop science literacy from an early age. Science literate individuals are better prepared to deal with complex issues such as climate change [17], health [18], and sustainable development [19]. They take responsibility for finding solutions to these issues.

The PISA study provides invaluable information on the strengths and weaknesses of science education systems worldwide [14]. By examining students' performance on a global scale, it highlights inequalities, identifies best practices, and provides a basis for improving educational policies [20]. PISA research differs from other international research in that it provides a normative value. In this way, other countries can evaluate their own levels according to this normative value. PISA tests started in 2000 and are organized every three years. An optional evaluation of an innovative field is part of the PISA evaluations. These include global competences in 2018, collaborative issue solving in 2015, complex problem solving in 2003, and learning techniques in 2000; 2021 includes creative thinking. This gives nations the chance to evaluate student performance from various angles [21].

When analyzing the PISA results, it was found that Kazakhstan was ranked low. In order to improve these results, the government of Kazakhstan is carrying out many projects and supporting the work done in this regard. In this context, the aim of our research was to analyze the educational policies of the countries participating and ranking in the PISA research and to provide recommendations for improving the quality of the educational process in the educational institutions of the Republic of Kazakhstan. In addition, our research aimed to identify pedagogical principles to improve science literacy among schoolchildren according to the standards of the PISA study and to empirically verify the effectiveness of these methods through empirical studies. In this context, the hypothesis of our research was “The design of teaching methods to improve the functional natural science literacy of schoolchildren in the Republic of Kazakhstan in accordance with certain pedagogical principles will meet the standards of the PISA study and increase student achievement in this area.”

2. METHOD

In this study, the results of China, Singapore, Hong Kong and Estonia, which received the best results in the 2018 PISA studies, were analyzed in terms of science literacy. In this context, descriptive content analysis will be performed in this study. The analyses will be compared with the results of Kazakhstan and pedagogical principles for creating science literacy in schoolchildren will be determined.

Content analyses are frequently used in social sciences, especially in educational sciences studies [22]. Finding the overall trend on the subject and directing future scholarly research within the parameters of the subject matter are the two main goals of content analysis studies. There are three ways to express content analyses: descriptive, meta-analytic, and meta-synthesis (thematic) [23]. Descriptive content analysis, which is the topic addressed in this study, is a systematic study that includes the evaluation of trends and research results in a descriptive dimension by considering all studies, published or unpublished, conducted within a specified topic [24]. In this context, in our research, academic studies on the relationship between PISA results and education policies of China, Singapore, Hong Kong and Estonia were analyzed. In this context, Google Scholar, ERIC, and Web of Science databases were analyzed in depth between 2010 and 2023, and research on the education policies of these countries and the results of the 2018 PISA assessments were included. In this context, literature related to keywords such as "science literacy", "PISA 2018 results", "education", "education policies" were searched in these databases. The relationship between the results of Kazakhstan and the top four countries was analyzed.

3. RESULTS AND DISCUSSION

3.1. Results

The reading, math, and science averages for China, Singapore, Hong Kong, and Estonia from the 2018 OECD are displayed in Figures 1-4. Approximately 98% of scientific students in B-S-J-Z (China) received a Level 2 or higher, significantly higher than the 78% average for all countries in the OECD. At the very least, these students are able to identify the correct explanation for well-known scientific occurrences and apply that understanding to assess the veracity of conclusions in simple situations by considering the relevant data. A total of 32% of students in B-S-J-Z (China) were proficient in science, meaning they were at Level 5 or 6 (OECD average: 7%). These students are capable of using their scientific knowledge in a variety of contexts, including ones they are not familiar with, in an autonomous and innovative manner as shown in Figure 1 [25].

Singaporean students performed far better than the OECD average of 78% for all countries, with 91% achieving Level 2 or above in science. At the very least, these students are able to identify the correct explanation for well-known scientific occurrences and apply that understanding to assess the veracity of conclusions in simple situations by considering the relevant data. More than 90% of students met this criteria in Beijing, Shanghai, Jiangsu, and Zhejiang (China) (98%), Macao (China) (94%), Estonia (91%) and Singapore (91%). In science, 21% of Singaporean pupils performed at the top of the class, OECD average of 7%, meaning they were proficient at Levels 5 or 6. These students possess the ability to independently and creatively apply their scientific knowledge to a wide range of contexts, including ones they are unfamiliar with, as presented in Figure 2 [25].

In Hong Kong, almost 88% of Chinese students received a scientific grade of Level 2 or higher (average for the OECD: 78%). At the very least, these students are able to identify the correct explanation for well-known scientific occurrences and apply that understanding to assess the veracity of conclusions in simple situations by considering the relevant data. More than 90% of students met this criteria in Beijing, Shanghai, Jiangsu, and Zhejiang (China) (98%), Macao (China) (94%), Estonia (91%) and Singapore (91%). An OECD average of 7% indicated that 8% of pupils in Hong Kong, China, were top performers in science, which translates to proficiency at Levels 5 or 6. These students possess the ability to independently and creatively apply their scientific knowledge to a wide range of contexts, including ones they are unfamiliar with, as displayed in Figure 3 [25].

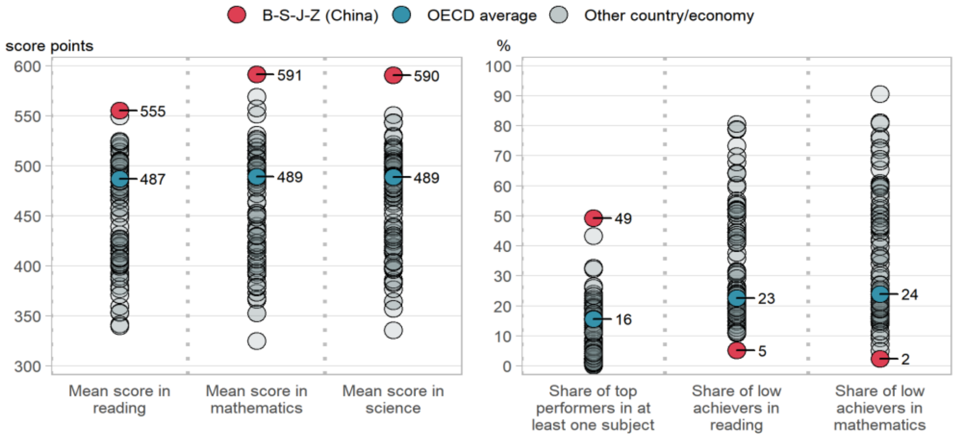

Figure 1. Performance in reading, math, and science of China

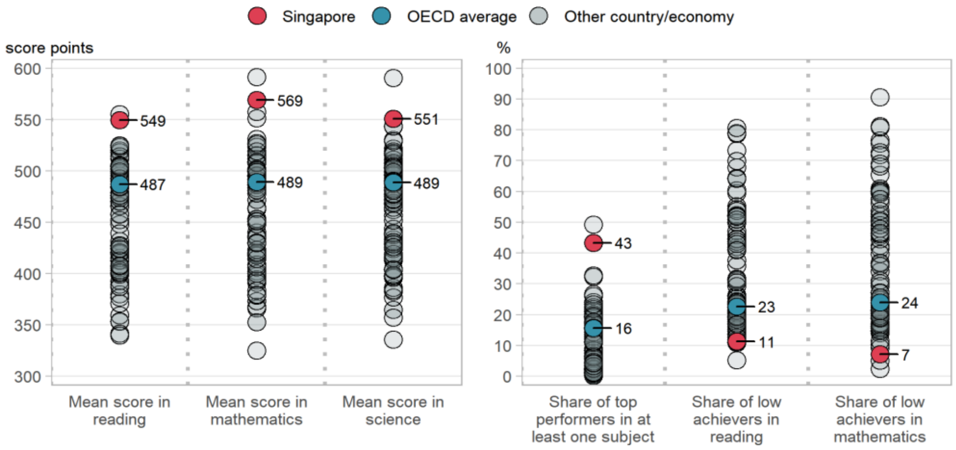

Figure 2. Performance in reading, math, and science of Singapore

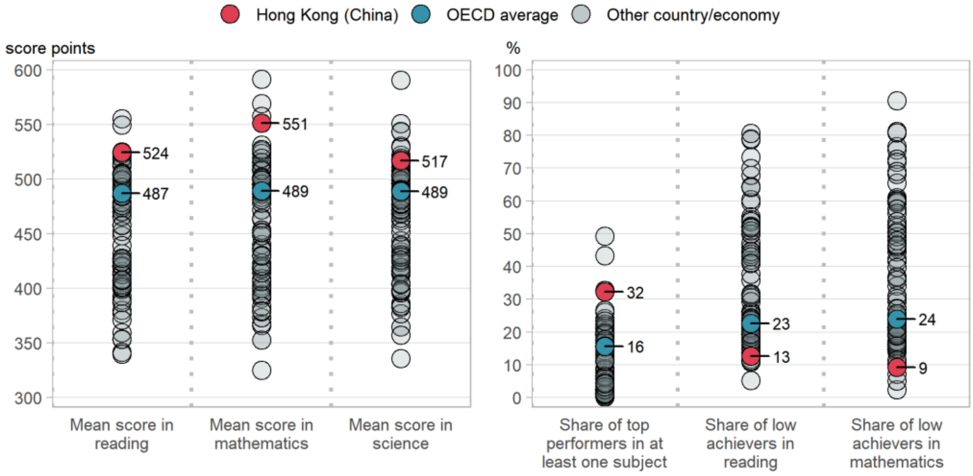

Figure 3. Performance in reading, math, and science of Hong Kong

In science, almost 91% of students in Estonia earned a Level 2 or higher, which is much more than the average for all OECD countries, which is 78%. At the very least, these students are able to identify the correct explanation for well-known scientific occurrences and apply that understanding to assess the veracity of conclusions in simple situations by considering the relevant data. More than 90% of students met this criteria in Beijing, Shanghai, Jiangsu, and Zhejiang (China) (98%), Macao (China) (94%), Estonia (91%) and Singapore (91%). In science, 12% of Estonian students excelled, corresponding to a Level 5 or 6 proficiency (OECD average: 7%). These students possess the ability to independently and creatively apply their scientific knowledge to a wide range of contexts, including ones they are unfamiliar with, as presented in Figure 4 [25].

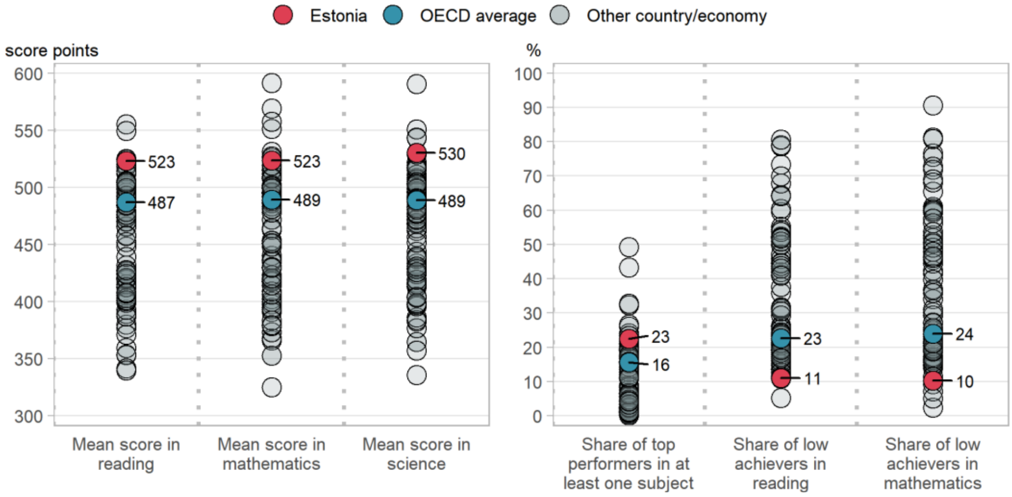

Figure 4. Performance in reading, math, and science of Estonia

Based on PISA 2018 findings, Figure 5 displays Kazakhstan's average scores in science, math, and reading. Based on these findings, about 40% of Kazakhstani pupils received a scientific grade of Level 2 or above (OECD average: 78%). These students can, at the very least, recognize the proper explanation for well-known scientific events and use that knowledge to determine whether a conclusion is true in straightforward circumstances based on the available facts. In science, only a small fraction of pupils in Kazakhstan achieved high performance, i.e., they were proficient at Level 5 or 6 (OECD average: 7%). These students possess the ability to independently and creatively apply their scientific knowledge to a wide range of contexts, including ones they are unfamiliar with [25]. In Table 1, the determinants of science literacy in China, Singapore, Hong Kong and Estonia, which ranked in the top four according to the 2018 PISA results, are analyzed in terms of endogenous and environmental variables [26]–[36].

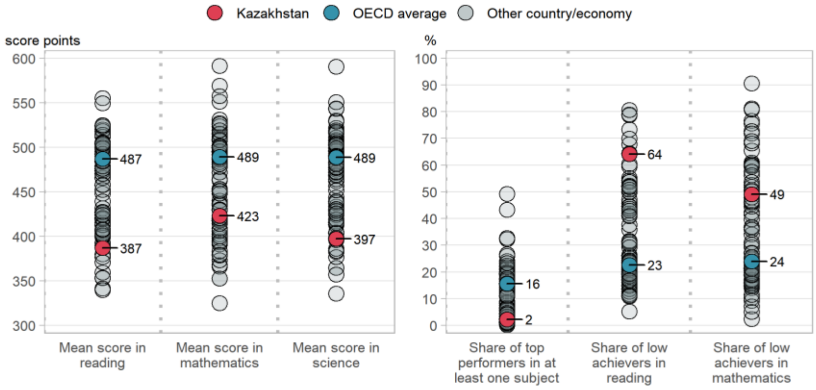

Figure 5. Kazakhstan's performance in reading, math, and science

Table 1. Examining the factors influencing the high ranking of the ranking countries in science literacy

Research	Target country	Key determinants of increasing scientific literacy
[26]	Singapore, Finland	At the student level, students' enjoyment and interest in science; at the school level, the economic, social and cultural status of schools are the most important predictors of scientific literacy in both countries.
[27]	China	- Scientists, science teachers and educational science experts as decision makers. - All stakeholders expressing their opinions and making joint decisions. - Analyzing the results of empirical research. - Empirical and scientific research on curriculum is supported by the government.
[28]	China, USA	- Metacognition, evaluating credibility, ability to summarize text, perception of difficulty and learning time in science were similar between the two countries. - Cooperation and competition between students helps the development of math and science. - Family economic status, self-awareness and learning environment are important. - Establishing policies to improve the abilities of students with low socioeconomic status
[29]	All countries participating in the 2015 PISA survey	In the ranking countries, - The quality of teachers' teaching practices, parents' professional/educational status, disciplinary climate, time spent on learning and participation, school equipment, number of teachers in the school, and students' status were identified as factors affecting science literacy. - It was concluded that the most important factor in demonstrating superior scientific performance is "Self-efficacy".
[30]	Australia, Canada, Ireland, New Zealand, UK, and USA	- Experience continuous questioning strategies - Frequency of teacher prompts and adaptive teaching strategies - Incorporating different components of research-based teaching
[31]	Turkey, Singapore, US, Korea, Italy, and Brazil	- The economic, social and cultural status of the school is the best predictor of science literacy. - Equity in education, - Questioning investments in leadership, teacher certification, number of students and teachers as they have minimal impact on science literacy
[32]	Singapore	- To discover and develop the talents and potential of young people to the fullest, - Develop a passion for lifelong learning, - Creating a flexible, diverse and broad-based education system, - Science curricula at all levels of education focus on science as inquiry and the knowledge, skills and processes, ethics and attitudes required, as well as an understanding of the impact of science in everyday life.
[33]	Singapore	- Science curriculum focusing on the theme of science, - Knowledge, skills and processes are important, as well as understanding the impact of science at all levels of education.
[34]	Hong Kong	Students' science literacy is significantly associated with parental involvement, even after controlling for student self-efficacy and school background factors. - Parental investment in cultural resources and the organization of early science learning enrichment activities, - Watching scientific documentaries, reading books about scientific discoveries, watching, reading or listening to science fiction are important in achieving success in science.
[35]	Hong Kong	- He made the case that the development of science literacy in early childhood settings is influenced by teacher preparation, educational policy, the home environment, and the community environment.
[36]	Estonia	- The views of science educators are in line with the literature. - Comprehensive instructional support systems, teacher, student and Estonian society's perspective on education are important in increasing science literacy, - It is also thought that Estonia's continued integration into Europe, with common values and attitudes in OECD countries, could weaken Estonia's education system and the qualities that propel students to this high status in PISA.

3.1.1. Kazakhstan and PISA

Kazakhstan entered the PISA survey for the first time in 2009. Initially, 5,590 students from 200 educational institutions participated in the study. Like every country that participated for the first time, Kazakhstan did not achieve the expected results [37] and ranked 58th out of 65 countries. Kazakhstan's PISA results by years are given in Figure 6. The figure illustrates that 2018 saw the lowest literacy results in Kazakhstan. The OECD's information indicates that incomplete student response data contributed to several issues with Kazakhstan's 2015 PISA scores. Accordingly, the OECD declared that 2018 saw Kazakhstan achieve the most trustworthy outcomes in science, including science literacy [25].

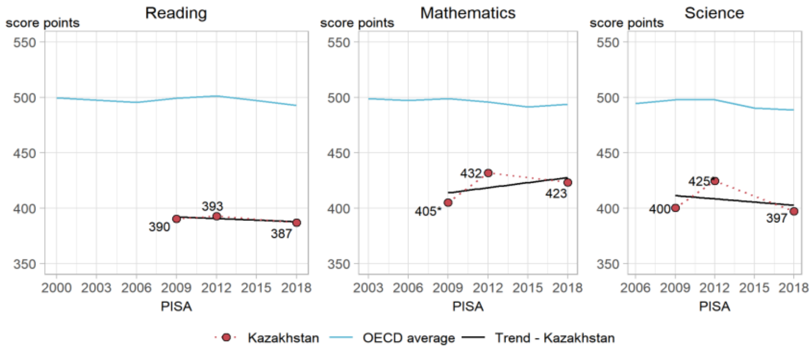

Figure 6. Kazakhstan's PISA results by year

3.2. Discussion

The objective of the study was to examine and compare the pedagogical principles used by the top-performing nations in the 2018 PISA study, with a focus on enhancing science literacy among schoolchildren. The study's conclusions, their ramifications, and any prospective effects on science education are all covered in great detail in the discussion section. Our study makes a concrete contribution to the field of education by providing actionable insights for educators and policy makers. By analyzing the pedagogical approaches of top-performing countries in PISA, we identify effective student-centered activities and learning environments that promote science literacy. We outline how these strategies can be adapted to different educational settings, taking into account local educational policies, resources and cultural contexts. Furthermore, our empirical analysis of PISA data from different socio-economic environments contributes to a better understanding of the factors that influence science literacy, guiding targeted interventions.

The study we conducted theoretically contributes to the discourse on science literacy by putting out a model that combines socioeconomic considerations, instructional tactics, and student participation. Future studies and theoretical advancements can build on this paradigm, especially when investigating the causal connections between these factors and the results of science literacy. By highlighting the significance of cultivating higher-order cognitive skills in student-centered learning contexts, it also questions established educational paradigms.

3.2.1. The role of student interest and enjoyment in science literacy

The importance of student engagement and enjoyment in science in predicting scientific literacy is one of the study's most notable findings. This result is consistent with earlier studies showing that students who are really curious about science and enjoy learning about it typically do higher on tests of scientific literacy [26], [29], [32]. It highlights how crucial it is to foster a sincere love of science in students. Teachers must work to make science interesting, relevant, and engaging because this will have a big impact on students' motivation to learn and do well in the subject. In Kazakhstan, 87% of students (OECD average: 67%) who gave a life satisfaction score between 7 and 10 indicated they were content with their lives.

Furthermore, 93% of students reported feeling joyful either occasionally or consistently, and 5% reported feeling down constantly. In most countries and economies, students were more likely to report feeling pleased when they reported having greater student cooperation and a stronger sense of belonging at school, and more likely to show dejection when bullying occurred more frequently. A total of 88% of students in Kazakhstan strongly agreed or agreed that they can usually find a way out of a difficult situation (OECD average: 84%), while 56% of students (OECD average: 56% of students) strongly agreed or agreed that they worry about what other people would think of them if they fail. In practically every school system, including Kazakhstan's, girls showed a larger fear of failing than boys did, and this gender gap was particularly noticeable among the most accomplished pupils. A growth mentality was exhibited by most students in OECD countries (they rejected or strongly disagreed with the statement "Your intelligence is something about you that you can't change very much"). 55% of pupils in Kazakhstan have a growth attitude [25]. In China, a country that has achieved significant success in PISA [38], students are less excited about their lives (56%) and some students are more likely to feel permanently unhappy than in Kazakhstan. Therefore, it is important to identify activities that will support students' all-round development [39]. Considering all these situations, it is thought that activities that improve students' self-qualities, exercises that focus on their own skills, practices that develop high-level skills such as problem solving [40] and critical thinking [41], and activities that focus on activities that improve students' cognitive, affective and psychomotor structures will positively affect the PISA results of students in Kazakhstan.

3.2.2. Socioeconomic status of schools

The socioeconomic situation of schools is another significant factor that this study emphasizes influences scientific literacy. This element affects student results at the school level and has a big impact [29], [42]. Schools in affluent neighborhoods typically have more resources, better infrastructure, and access to qualified teachers, which can result in higher educational outcomes. The results of the study highlight the necessity of implementing educational policies and initiatives that address inequalities in school funding and resources in order to give every student the same chance to succeed in science [43], [44]. Alivernini and Manganelli examined the socioeconomic dimensions of science literacy in 25 countries and concluded that teachers' salaries, parental pressure on schools, the physical structure of the school, environmental factors, and socioeconomic status affect the scores obtained in PISA studies [45]. Similarly, Kalkan *et al*. [31] argued that economic, social and cultural status are important factors affecting scientific literacy. In the case of Kazakhstan, the number of migrants in 2018 was 8%, while in 2012 it was around 12%. One third of these migrant students were socioeconomically disadvantaged. Although there was a difference in reading performance between immigrants and non-immigrants, this was not the case in scientific literacy. In fact, 20% of migrants performed above the OECD average. In this case, it can be considered that the adaptation of immigrants to the education system in Kazakhstan over the years has been achieved in the fields of mathematics and science literacy. However, it is thought that the difference between immigrants and non-immigrants in language teaching will positively affect the performance in other fields of science [46]. Therefore, it is recommended to conduct studies in this field.

3.2.3. Implications for pedagogy

The study's comparative research of educational practices in high-performing nations has produced insightful findings about the methods that support improved science literacy. The discovery of these principles offers a basis for the development of successful pedagogical approaches to science education. These concepts might support inquiry-based, experiential learning, the utilization of real-world examples, and the development of critical thinking and problem-solving abilities [47], [48]. In another perspective, Elvisto and Sisko argued that Estonia's success in PISA is not only a product of its education system, but also reflects broader societal values and holistic support of teaching systems, teachers and society that foster an enabling environment for science literacy; however, homogenization of educational standards and attitudes through further integration with Europe poses potential challenges for the diverse educational culture that contributed to Estonia's exceptional performance [36]. Additionally, research indicates that teacher quality has an impact on students' PISA results. High standards for hiring teachers, successful programs for preparing them, and chances for professional growth all contribute to this [49]. Effective pre-service teacher education and ongoing professional development are thought to improve teacher quality.

Additionally, high-performing systems are dedicated to enhancing the caliber of their in-service educators by offering them a wealth of materials and opportunity for ongoing professional development [50], [51]. Singapore, one of the successful countries, has become an object of emulation for many countries [52]–[54]. When the reasons underlying this situation are examined, it is thought that among the main factors in the success in science is that students carry out the activities by doing and experiencing and analyze the findings obtained [55]–[57]. This situation enables students to learn on their own and makes learning permanent [58]–[60]. Thus, PISA results play a critical role in evaluating the effectiveness of pedagogical approaches and provide a guiding source for the development of educational policies.

The differences between Kazakhstan's education system and the education systems of the countries that came first in the PISA results are quite striking. Although Kazakhstan has significantly improved its educational reforms in recent years, it is thought that it will take time for this situation to become widespread. In this context, it is thought that teachers are more likely to adopt traditional teaching methods. However, countries that have achieved success have adopted student-centered, experiment-based learning approaches. In particular, countries such as China, Singapore, Estonia and Hong Kong follow a system that encourages students' participation in their own learning processes and makes curricula flexible according to students' interests and needs. In addition, in these countries, the continuous investment in the professional development of teachers and the constant review of educational policies stand out as an important difference. The education system in these countries plays an active role in preparing students for today's complex world by focusing on developing skills such as critical thinking, problem solving and collaboration. Therefore, the need for change and transformation in the education systems of countries like Kazakhstan comes to the fore.

4. CONCLUSION

The pursuit of scientific literacy among school-age children is no longer an educational goal, but an essential life skill. Scientific literacy is a gateway to understanding and engaging with the complexities of our modern world. It empowers people to make knowledgeable decisions regarding a wide range of global challenges, including technology, the environment, and health. The foundation for well-informed, practical, and creative solutions is scientific literacy, which is essential when it comes to managing pandemics and tackling climate change. There has never been a better time to promote scientific literacy, and this study has shown Kazakhstan the way forward. Uncovering the factors underlying high-performing nations' achievement was made possible by the study's novel method of comparing educational procedures in these nations. Through the analysis of nations that continuously demonstrate exceptional science literacy, the research unearthed a wealth of pedagogical insights that support successful science instruction. It is impossible to overestimate the significance of this comparative analysis because it has shed light on aspects of science education that merit more consideration. The research has yielded educational concepts that provide a robust basis for the creation of transformational instructional approaches. The aforementioned approaches prioritize the significance of inquiry-based learning, hands-on experiential education, integration of real-world applications, and development of critical thinking and problem-solving skills. This new paradigm of teaching and learning creates a very relevant, interactive, and engaging learning environment.

In this context, when the main characteristics of successful countries are analyzed, determining effective teaching methods, developing programs focusing on science literacy, continuing teacher training and development, encouraging student-centered approaches, ensuring active participation of family and community in education and training processes, and improving assessment and feedback processes stand out as some of the main criteria for success in PISA. Preferring active and active participatory learning approaches rather than traditional science education, determining student-centered approaches rather than teacher-centered educational activities, preferring examinations that develop students' high-level cognitive skills such as problem solving and critical thinking by integrating technology rather than routine examination systems are important keystones in achieving success goals.

According to the results of our study, we have some suggestions for students, teachers and policy makers. Students should actively participate in the process for scientific literacy, learning based on experiments and practical applications should be reinforced. It should provide real life integration. Actively use critical thinking and problem-solving skills. Teachers should continuously develop transformative education methods, create an engaging learning environment, use high level assessment and evaluation tools, and support the active participation of family and community. Policy makers should increase spending on education, develop policies for student-centered approaches, examine assessment and feedback processes and create opportunities for active learning approaches.

ACKNOWLEDGEMENTS

The Republic of Kazakhstan's Ministry of Science and Higher Education provided funding for this work under grant number AP14872059. We acknowledge the Republic of Kazakhstan's Ministry of Science and Higher Education for this.

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