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Original Research

A Multidimensional Framework for Measuring Scientific Leadership

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Abstract

Scientific progress has been one of the critical concerns of many nations in recent decades. It has become one of the top priorities at the highest policy-making levels in several countries. During the last two decades, several policies have been developed to achieve scientific progress and leadership in different parts of the world. For example, China, Japan, Turkey, Saudi Arabia, and Iran have designed their policies to accelerate scientific progress and achieve scientific leadership in a specific region. However, there is no comprehensive framework to measure the extent of scientific leadership in theory or practice. This study proposes a multidimensional framework for measuring scientific leadership in countries through a qualitative approach. To address this objective, key dimensions, indicators, and metrics for measuring scientific leadership were identified in the literature and policy documents. After the identification of these dimensions, indicators, and metrics, they were verified and weighted by different expert panels. According to the findings, a comprehensive framework for measuring scientific leadership includes five dimensions and 22 indicators and metrics. Results showed that "institutions" is more important than other dimensions in the framework. Since the nature of "scientific leadership" concept is more political than scientific, considering dimensions and indicators covered by the media is a more effective way to measure it. The findings of this study can give policymakers a more comprehensive and accurate view of the concept of scientific leadership and assist them in various planning and research policies. In addition, the proposed framework is the basis for future research seeking to assess scientific leadership quantitatively.

Keywords: Scientific Leadership, Scientometrics, Science Policy, Research Outputs.

Introduction

The production of knowledge is the basis of ability. The production of science and knowledge is achieved only through research. A dynamic economy is pursued by development based on knowledge. Therefore, the production of science increases knowledge that paves the way for technology and, as a result, the production of employment and wealth, ultimately leading to comfort, ability, and social security. One of the indicators of growth and development of any country is its actual scientific capacity. Upgrading this capability depends on improving the status of scientific knowledge outputs, which research investments and activities help to reach this situation. Since the increase and deepening of research activities are the primary basis for development, today, a significant part of the facilities of the world's developed countries is spent on research. Therefore, different countries try to increase their role in political, economic, and scientific relations by increasing their share in the creation of world science.

"Scientific progress" or "scientific development" is no longer a desire today but an intellectual paradigm. In today's world, which Toffler (1980) believes is experiencing an "information age", the value of information seems to be greater than ever. For this reason, attention has been paid to scientific issues and information creation, storage, and utilization in various countries. Countries are engaged in tremendous and close competition to create science and seek to surpass each other. Increasing the number of higher education institutions, attracting more students and researchers, and increasing research and development costs are signs of world countries' efforts to achieve a better position in science.

Many believe that to achieve development in the economic, social, cultural, political, security, health and other dimensions of society, one must pay attention to science and scientific research (Sener & Seridogan, 2011). Therefore, scientific development can lead to national development and improve society's welfare. Today, countries' power is no longer measured solely by the number of their financial assets and military power. Science, technology, and innovation are considered a symbol of human endeavor to achieve a better life. Its importance is such that a large part of the development of countries is evaluated based on their scientific and technological achievements. Countries that are trying to prove their power in the international community, have invested in science and technology more and more on their agenda (Noroozi Chakoli, Hassanzadeh, Etemadifar & Noormohammadi, 2009: 2).

Given the role of scientific development in society, countries' political leaders have also paid special attention to this issue in recent decades. Many countries have invested heavily in scientific development and have developed programs and policies in this area. For example, the Secretary-General of the Communist Party and the President of China proposed a policy called the concept of scientific progress as one of China's key perspectives (Fewsmith, 2004). This policy was formulated in the Congress of this country in 2007, and since 2008, extensive activities have been carried out in this field. Iran, Turkey, Japan, India, Saudi Arabia, and many other countries have brought scientific development to political circles and established comprehensive policies in this area.

The French Observatory of Science and Technology has introduced the concept of "scientific dynamics" and in the report on the dynamics of scientific production in the world, Europe and France, 2000-2016, has evaluated the following indicators to measure scientific dynamics: (1) Gross internal costs for research and development of non-profit organizations; (2) GDP; (3) Scientific publications; (4) The share of publications as a percentage of total global publications; (5) Share of citations within three years; (6) Share of highly cited publications (top 1%); and (7) The share of Nobel winners (OST, 2019). Accordingly, the report propounds that countries with a high share and rank in the mentioned indicators have a higher position in science among other countries.

Shi and Gong (2012) consider the "global leader in science and technology" a concept comparable to the "world science center". According to him, the Japanese historian Mintomu Yuasa believes that a country that produces more than 25% of the world's scientific achievements can be recognized as a world science center. World leaders in science and technology are not necessarily those countries that are part of the world's scientific centers but are similar in scientific and technical development. Basu, Foland, Holdridge and Shelton (2018) states that a nation's "global leadership" can include many dimensions, such as military, economic, scientific, technological, medical, environmental, and so on. Quantitative indicators are R&D investment, article, citation, patent, and GDP. Boyack and Clavans (2009) argue that the traditional way to measure countries' "scientific power" is to calculate articles or citations by discipline. Sources such as biennial science and engineering indicators Reports (SEI) track these indicators and indicates national leadership trends.

Abramo et al. (2009) are researchers who have dealt with similar concepts of authority and leadership. In their view, studying the concept of "scientific excellence" and its methods of measuring and evaluating has become increasingly important in developing research policies in many countries. This indicator provides the ability to successfully identify higher national centers and the possibility of higher allocation in research funding (Suresh & Thanuskodi, 2019).

It seems that the concept of scientific authority or leadership can be imagined as an umbrella that covers the fields of science (academic research), technology and innovation (in the form of knowledge-based products), and education (academic and university). On the other hand, scientific leadership can be considered at the level of an individual, university, research center, specific subject area, journal, article, or country. Thus, it is necessary to have a comprehensive view of this concept to predict and implement suitable strategies to follow this path.

In general, the concept of scientific leadership has not been specifically and wholly addressed in research, and its dimensions are not fully clear. To rank countries in terms of scientific power, developing a precise tool and framework is necessary. The present study seeks to establish a specific framework for measuring scientific leadership by addressing three main objectives: (1) Exploring global indicators and indexes for measuring scientific leadership, (2) Validating the scientific leadership assessment framework using science and technology experts' opinions, and (3) Weighing each dimension and indicators of scientific leadership assessment framework.

Background

Zhou and Leydesdorff (2006) state that China has become the fifth leading country in the world in terms of the share of scientific publications. The citation to articles with Chinese affiliation for authors also shows exponential growth. In particular, China has become a significant player in essential technologies such as nanotechnology. They argue that while it is challenging to map nanoscience and nanotechnology, they show that China has recently reached a position behind the United States. The country's research and development budget has increased significantly since 1997.

"Leadership of Thought: A New Index for National and Institutional Comparison" is a study by Klavanz and Boyack (2008). In this study, a new method for evaluating the activities of national publications is introduced. This new indicator, intellectual leadership, indicates whether a country is an intellectual leader (using the recently cited literature for that field) or a follower (using the old cited literature of that field). Publication data are used to indicate which countries are willing to act on recent findings in chemistry and clinical medicine. The leadership of thought focuses on the age of resources representative of the current publication. If a representative acts based on newer findings in his field, he is considered a leading factor.

Shelton and Foland (2010) claimed that the United States and the European Union are trying to lead science and technology, but now the People's Republic of China has overtaken it. The United States is a leader in most input indicators, but the European Union is a leader in essential outputs. Estimates of the current situation and the rate of recent change indicate that China will soon compete with others as a scientific superpower in many respects. If the current investment trend continues, the United States and the European Union are expected to continue their downward trend, while China is expected to equal them in the science citation index within ten years. There is some confirmation from other databases, as China has already surpassed the United States in the Inspec and Compendex systems.

Khoubnasabjafari, Sadeghifar, Khalili, Ansarin & Jouyban (2012) assessed the scientific performance of Islamic Cooperation member countries. In this study, the number of articles and inventions registered by members of the Organization of the Islamic Conference, along with the top journals, authors, type of document, universities, the language of publications, and topics extracted from Scopus, was the basis for comparing countries. Hardman, Van Roy, Vertsi and Saisana (2014) presented a report entitled: Analysis of National Research Systems: A Combined Index for Scientific and Technological Research Excellence. After evaluating the qualitative characteristics, a large set of potential variables are focused on four variables to measure the high-quality production of scientific and technological research activities at the national level: (1) a field-normalized number of highly cited publications of a country as measured by the top10 % most cited publications (in all disciplines) per total number of publications (HICIT); (2) Number of high quality patent applications; (3) Number of world-class universities and research institutes; and (4) Number of high-credit research grants.

Leydesdorff, Wenger and Bornman (2014) compared the EU, China, and the United States to the top 1% and 10% of citation publications. Accordingly, a global comparison of the EU, the US, and China show a high level of dynamism that differs from their analysis in terms of the share of publications: the US is highly productive in 1% of the top articles, and China is out of competition. The elite leaves.

Gul, Nisa, Shah, Gupta, Jan & Ahmad (2015) conducted a study to evaluate Middle Eastern countries' research productivity and performance. The criteria for evaluation included the following six items: documents indexed on the Science Web, the volume of citations received, average citation per document, percentage of citations, impact on other countries, and overall performance. Bornmann, Wenger and Leydesdorff (2015) believe that the BRICS countries (Brazil, Russia, India, China and South Africa) are known for their increased participation in science and technology. The researchers examined the situation of these countries in highly cited articles (top 10% and top 1% cited articles) between 1990 and 2010.

Siddiqui, Stoppani, Anadon & Narayanamurti (2016) used three criteria: a classical productivity criterion (volume of publications per person), and an adaptation criterion that was identified as a scientific advantage (from which to compare publications in scientific fields between countries). It is used to describe expertise in the field, and the new index of scientific localism (defined as the ratio of publications in collaboration with local authors) to determine the capacity for scientific absorption. In his study to find trends, Cavacini (2016) compared the scientific output of 16 Middle Eastern countries from 1996-2014 with 27 countries in Western Europe and, on average, world production. The data show that during 1996-2014, Israel was the leading country in the Middle East in terms of the total number of citations and total citations per document, while Turkey and Iran are in the lead in terms of scientific articles produced in this field. In terms of scientific outputs, Egypt and Saudi Arabia came from emerging Middle Eastern countries.

Moed (2016), in his research, states that the longitudinal analysis of bibliographic data indexed in Incites and Scopus related to the Persian Gulf countries and the Middle East neighbor shows the apparent effects of critical political events over the past 35 years. In 2015, Iran became the leading country in the Persian Gulf and Southeast Asia, including China, Malaysia, and South Korea, as a significant scientific partner, displacing the United States and other major Western countries. The study by Shashnov and Kotsemir (2018) provides a comprehensive analysis of the research perspective in the BRICS countries from different aspects: the level of their research activities and their contribution to the global process of scientific products. Subject structure of publications of these countries, their scientific expertise; Quality of articles measured by citation indicators similarity of subject structures of publications; Characteristics of international research cooperation and finally, the proximity and relative influence of each country in internal cooperation pairs.

Wanger, Whetsell, Baas and Jonkers (2018) argue that the rapid increase in international cooperation over the past three decades has been demonstrated by the collaboration of the authors of scientific papers. They found that openness among advanced scientific systems is strongly associated with "impact" - the more a country engages in international cooperation and mobility of researchers, the more significant the impact of scientific work. The results of this study provide important considerations for investment policies and the exchange of students, researchers, and technical staff.

Haq and Tanveer (2020) conducted a study to assess the productivity of research, the status of higher education and scientists among members of the Organization of Islamic Cooperation. The data of this retrospective study were extracted from online sources with open access and research productivity records and the number of journals and other source publications from the SCImago Journal and Country Rank (SJR). The number of quality universities, the number of researchers per million, and the number of internationally indexed journals were among the indicators used.

Fazeli-Varzaneh, Ghaderi-Azad & Elango (2020) conducted a study to review the results of engineering research in Middle Eastern countries. Data were collected from the Web of Science and analyzed by criteria such as average annual growth, compound annual growth rate, activity index, and relative specialty index. Moreover, the level of regional and international cooperation in the Middle East was also determined. Li, Zhang and Liu (2020) designed and proposed a new method called: The method of identifying the scientific ability resulting from the citation, which is used to measure the scientific capacity of a country in terms of scientific maps that the country is responsible for in scientific research.

A review of research conducted in this field in recent years shows that attention is paid to measuring the scientific potential of countries. On the other hand, paying attention to these studies shows the efforts and focus of researchers on different dimensions and levels of scientific excellence. In addition, no independent research was found that examined the levels, dimensions, and various scientific indicators.

Materials and Methods

This research is a descriptive-analytical study conducted through a quantitative approach. This research was conducted in two main steps (Figure 1). In the first step, academic research and policy documents identified the key indicators and metrics related to scientific leadership. To identify dimensions, indicators, and metrics for measuring scientific leadership, national and global bibliographic databases were explored, policy documents and national laws were reviewed, and a pool of these dimensions, indicators, and metrics was created.

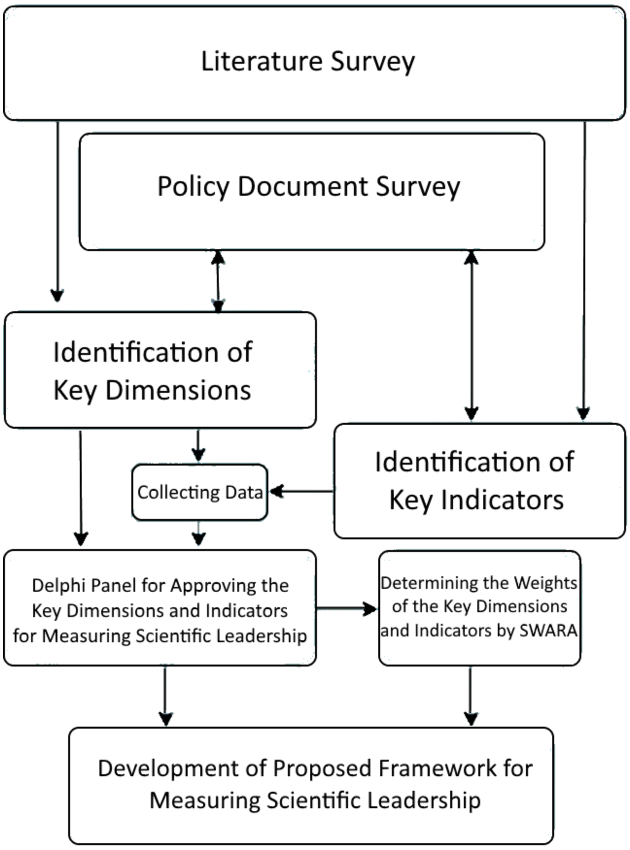

Figure 1: The research process and steps

After constructing a pool of dimensions, indicators, and metrics, researchers developed the initial framework for measuring scientific leadership based on theoretical and practical literature. The initial framework for measuring scientific leadership included five main dimensions (i.e., authors, institutes, subject areas, journals, and research outputs) and 59 indicators and metrics. For selecting dimensions, indicators, and metrics for measuring scientific leadership, an expert panel including 15 experts from the Supreme Council of the Cultural Revolution, Scientific Policy Research Center, Isfahan University of Medical Sciences, Payame Noor University, Shiraz University, Research Institute of Information Science and Technology, Birjand University of Medical Sciences, and Shahed University helped researchers to conduct this step. Different experts affiliated with an academic institution as faculty members or working as a professional in the field of science and technology policy making were selected.

These dimensions, indicators, and metrics needed to be approved by experts to fit into the final framework of measuring scientific leadership. Hence, in the second step, the initial framework was verified using an expert panel. This panel included 20 experts from the Supreme Council of the Cultural Revolution, Scientific Policy Research Center, Isfahan University of Medical Sciences, Payame Noor University, Shiraz University, Research Institute of

Information Science and Technology, Birjand University of Medical Sciences, and Shahed University. The first step in determining test validity is to check the content validity. One of these methods is the "content validity ratio index" (CVR). To calculate this index, experts' opinions in the field of test content are used. By explaining the test objectives to them and providing them with operational definitions related to the content of the questions, they are asked to rate each question based on a three-part spectrum. Likert classifies "necessary","useful but unnecessary," and "unnecessary". Then, according to the following formula, the content validity ratio is calculated:

The minimum acceptable CVR will vary depending on the number of professionals who have evaluated the questions. Questions for which the calculated CVR value is less than the desired amount according to the number of experts assess the question are excluded from the test because they do not have acceptable content validity based on the content validity index (Ayre & Scally, 2014).

The list of indicators for this research questionnaire was sent to 13 experts in this field via email. In this step, experts in science and technology policy making were identified at the national and international levels. The expert panel was established based on the two mentioned criteria. The identification of international experts was made possible by a thematic search in global databases and citation indices. These experts were from India, China, the United States, the Netherlands, and the Arab region.

According to existing standards, the minimum acceptable CVR value based on this number of scoring professionals is 0.54. In this way, the indicators lower than this amount removed from the list of studied indicators, and other items were preserved.

Results

Initial Framework for Measuring Scientific Leadership

First, the proposed framework for measuring leadership includes global indicators in the scientific system's five components and has the top institutions (universities and research centers), outstanding people (researchers and scientists); leading subject areas, top journals, and articles. For using a questionnaire, it is exposed to the judgment of science and technology evaluation experts so that they can approve or disapprove them and to each of the components or indicators based on their importance in the scientific leadership of a score between 1 (least important) and 10 (most important). Table 1 illustrates the initial framework for measuring scientific leadership

Table 1
The initial framework for measuring scientific leadership

Component	Indicators	CVR
Researchers	Percentage of research and development workers	0.47
	Share in the of the world's top one percent of scientists	0.43
	Number of highly cited researchers	0.69
	Number of researchers with hot papers on Web of Science	0.68
	Rising stars	0.42
	Number of researchers with patent	0.51
Academic Journals	Total number of scientific journals	0.47
	Number of journals indexed in the SJR database	0.83
	Medium impact factor of journals based on SJR data	0.71
	Scopus Specific Impact Factor (Cite Score)	0.88
	Source Normalized Impact Factor (SNIP)	0.85
	Number of Q1 journals (based on SJR impact factor)	0.61
	Number of Q2 journals	0.50
	Number of Q3 journals	0.48
	Number of Q4 journals	0.46
Research Outputs	Total number of papers published on the Web of Science	0.61
	Total number of papers published in Scopus	0.52
	Country share of papers published in Web of Science World	0.79
	Country share of world papers published in Scopus	0.50
	Number of citations per paper	0.77
	H index	0.80
	Number of hot papers	0.49
	Ratio of hot papers to all papers in the country	0.71
	Number of highly cited papers	0.48
	Ratio of highly cited papers to all papers in the country	0.69
	Percentage of papers published in Q1 journals	0.60
	Percentage of papers published in Q2 journals	0.51
	Percentage of papers published in Q3 journals	0.49
	Percentage of papers published in Q4 journals	0.47
	Percentage of joint papers (international collaborations)	0.63
	Number of leading papers	0.48
Research Areas	Nature Index Rank	0.81
	Scientific and technical papers (from World Bank data)	0.42
	Field-Weighted Citation Impact	0.74
	Researchers' contribution to research papers published in Research Fronts	0.70
	Number of institutions in the Times Higher Education (THE) (academic subjects)	0.61
	Number of institutions in the QS ranking (academic subjects)	0.51
	Number of institutions in the US News ranking (academic subjects)	0.49
	Number of institutions in Round University Ranking (academic subjects)	0.50
	Number of institutions in the Shanghai Ranking (academic subjects)	0.48
	Number of prominent Topics	0.47
	Number of Fast Moving Fronts	0.49
	Number of research fronts	0.51
Number of top	US News Ranking	0.50

Component	Indicators	CVR
institutions (universities and research centers) in international ranking systems	Times Ranking	0.79
	Shanghai Ranking	0.50
	Scimago Ranking	0.49
	QS Ranking	0.68
	Leiden Ranking	0.48
	Urap Ranking	0.46
	ISC Ranking	0.48
	Green Metric Ranking	0.44
	Rur Ranking	0.43
	Round Ranking	0.47
	Nature Index Ranking	0.45
	Taiwan Ranking	0.44
	ITU Ranking	0.46
	U-Multirank Ranking	0.46

Approved Framework for Measuring Scientific Leadership

In fact, 59 indicators were initially counted and predicted for measuring leadership, but after validation, their number was reduced to 22. The list of indicators is shown in Table 2.

Table 2
Approved framework for measuring scientific leadership

Component	Component Code	indicators	Indicators' code	average score
Researchers	A	Number of highly cited researchers	A2	6.14
		Number of researchers with hot papers in Web of Science	A3	5.71
Academic Journals	B	Number of journals indexed in the SJR database	B1	5.47
		Medium impact factor of journals based on SJR data	B2	5.47
		Scopus Specific Impact Factor (Cite Score)	B3	5.83
		Source Normalized Impact Factor (SNIP)	B4	5.78
		Number of Q1 journals (based on SJR impact factor)	B5	7.40
Research Outputs	C	Total number of papers published in Web of Science	C1	7.11
		Country share of papers published in Web of Science World	C2	7.38
		number of citations per paper	C3	7.09
		H index	C4	6.69
		Ratio of hot papers to all papers in the country	C5	6.81
		Ratio of highly cited papers to all papers in the country	C6	7.02
		Percentage of papers published in Q1 journals	C7	6.69

Component	Component Code	indicators	Indicators' code	average score
		Percentage of joint papers (international collaborations)	C8	6.73
Research Areas	D	Nature Index Rank	D1	7.00
		Field-Weighted Citation Impact	D2	6.52
		Researchers' contribution to research papers published in Research Fronts	D3	6.64
		Number of institutions in the Times Higher Education (THE) (academic subjects)	D4	5.85
Institutions	E	Number of Institutes in QS Ranking	E1	6.95
		Number of Institutes in THE Ranking	E2	8.45
		Number of Institutes in Shanghai Ranking	E3	7.42

Final Framework for Measuring Scientific Leadership: Results of SWARA Method

Finally, based on the views of researchers and experts in science and technology policy-making, the framework for measuring scientific leadership can be considered to consist of five key dimensions. In other words, five dimensions must be evaluated to compare the scientific leadership of different countries. These five dimensions are illustrated in Figure 2.

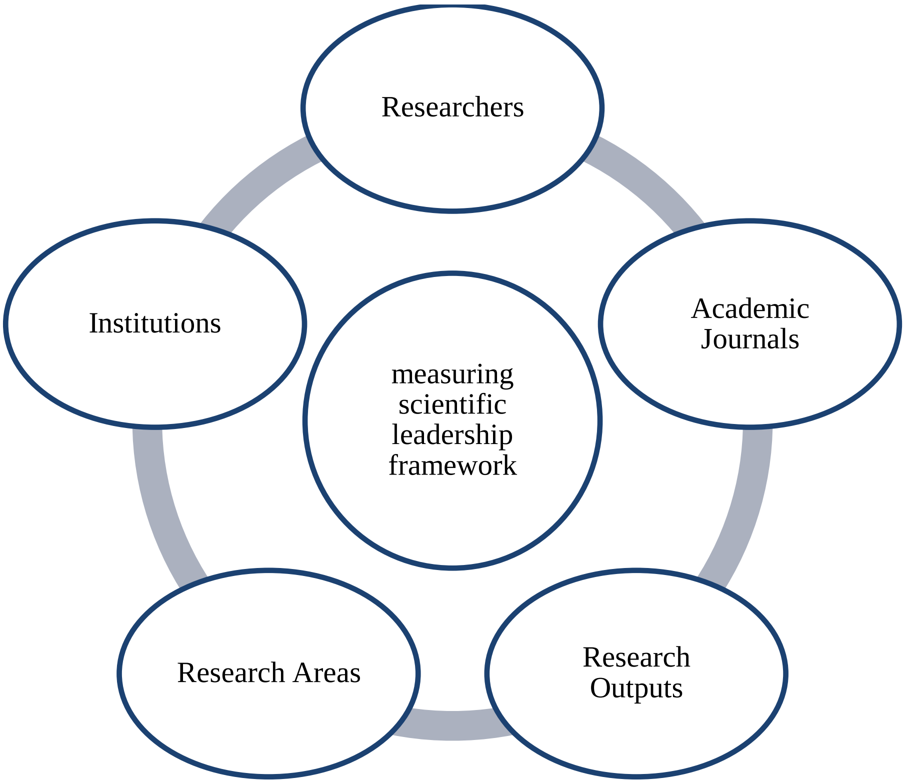

Figure 2: Main dimensions of the measuring scientific leadership framework

However, according to the opinions of researchers and experts, the dimension of “institutions” seems to be more important than other dimensions in measuring scientific leadership. The first step for clarifying the importance of different dimensions and indicators is to sort the indicators by descending order (from high to low). This process can be done using the average scores given in Table 3. To calculate the weight of the main criteria, we first calculate the average Likert scores of the sub-criteria of each criterion to determine the main criterion score. Then, the criteria are sorted in descending order based on the average score and, similarly to the algorithm. The weights of the criteria are calculated as shown in Table 3.

Table 3
Final framework for measuring scientific leadership

Component	Component weight	Indicators	Relative weight of the sub-criteria	Final weight of the sub-criteria	Rank
Researchers	0.120	Number of highly cited researchers	0.313	0.0375	10
		Number of researchers with hot papers in Web of Science	0.219	0.0262	14
Academic Journals	0.102	Number of journals indexed in the SJR database	0.122	0.0124	23
		Medium impact factor of journals based on SJR data	0.122	0.0124	22
		Scopus Specific Impact Factor (Cite Score)	0.167	0.0170	20
		Source Normalized Impact Factor (SNIP)	0.160	0.0163	21
		Number of Q1 journals (based on SJR impact factor)	0.430	0.0438	6
Research Outputs	0.231	Total number of papers published on the Web of Science	0.144	0.0333	11
		Country share of papers published in Web of Science World	0.182	0.0420	8
		number of citations per paper	0.141	0.0325	12
		H index	0.096	0.0223	18
		Ratio of hot papers to all papers in the country	0.108	0.0250	15
		Ratio of highly cited papers to all papers in the country	0.131	0.0303	13
		Percentage of papers published in Q1 journals	0.096	0.0223	18
		Percentage of joint papers (international collaborations)	0.101	0.0233	16
Research Areas	0.161	Nature Index Rank	0.358	0.0577	4
		Field-Weighted Citation Impact	0.236	0.0380	9
		Researchers' contribution to research papers published in Research Fronts	0.264	0.0425	7
		Number of institutions in the Times Higher Education (THE) (academic subjects)	0.142	0.0228	17
Institutions	0.385	Number of Institutes in QS Ranking	0.183	0.0705	3

Component	Component weight	Indicators	Relative weight of the sub-criteria	Final weight of the sub-criteria	Rank
		Number of Institutes in THE Ranking	0.547	0.2105	1
		Number of Institutes in Shanghai Ranking	0.270	0.104	2

Discussion

The concept of scientific leadership has been in the focus of science and practice for (at least) the last half century, perhaps because of the increasing role of science and research in the development of societies (Nabavi & Rasuli, 2021). However, scientific leadership can be argued at various levels (Simoes & Crespo, 2022), from the individual and research team levels to the institutional and country levels. Each of these levels has its characteristics, and applying a specific framework or indicator to measure scientific leadership at one level may be different from the others. The current study focused on exploring scientific leadership at the country level.

Some countries have entered scientific leadership into their science and research policy, and science policymakers use this concept in their speeches (Fewsmith, 2004). The general idea of this concept is that a country is in a better position than other countries in various fields. However, it seems this concept is more political than scientific. In other words, countries - especially those competing with each other - use such a concept for political purposes. For example, China's scientific leadership is developed to compete with the United States, and Iran's scientific leadership competes with countries in its geographical region. But this political concept has paved the way for academic writings and is being studied.

However, scientific leadership is not an objective concept, perhaps because there is no clear definition of this concept and there is no consensus on what it is (Nabavi & Rasuli, 2021). Many studies on this subject have explored not all of its dimensions, but limited dimensions. The lack of a conceptual framework in this area has led to confusion that are sometimes seen in science and research policies. For example, Iran refers to this concept in policy documents without giving objective indicators for measuring that. This research attempted to develop a comprehensive framework for measuring scientific leadership at the country level.

The findings of this study showed that to measure scientific leadership, in addition to qualitative criteria, a quantitative framework is required to compare countries with each other. Therefore, the proposed framework in this research can be a key step toward assessing scientific leadership. According to experts, the assessment of scientific leadership can be measured based on five dimensions and 22 indicators.

It should be noted that the science ecosystem in a country has different dimensions. For example, Pandey and Pattnaik (2015) believe that the ecosystem of science has dimensions such as human capital (such as researchers and faculties), governance capital (such as rules and policies), physical capital (such as land and equipment), intellectual capital (such as information and ideas), and financial capital (such as research grants and funding). In addition, ‘Committee on Science, Engineering, and Public Policy’ (2000, 152), affiliated to National Academy of Sciences, believes that scientific leadership in the field of material science and technology should include six main dimensions: national imperatives, innovation, major facilities, centers, human resources, and funding. However, the findings of this study showed that experts, in measuring scientific leadership, pay more attention to the outputs, outcomes, and impact than to the inputs of the science ecosystem.

Most of the indicators of scientific leadership that experts have considered are global indicators whose data are collected from international databases such as the Web of Science and Scopus. Applying these indicators in order to measure scientific leadership is a double-edged sword. On the one hand, only global indicators can be used to compare different countries, not local ones. Therefore, global indicators may be appropriate to assess the scientific leadership of countries relative to each other. On the other hand, global indicators cannot properly demonstrate the potential of different countries. For example, many of Iran's research outputs are in Persian; but these outputs are ignored in global reports and indicators. International reports are considered mostly English-language outputs. Hence, considering global indicators can ignore part of the domestic scientific strength of countries.

The findings showed that the most important dimension in assessing scientific leadership is "institutions," the key indicator in this dimension is "the number of institutions in the Times Higher Education University Ranking". One reason for this may be that: “n*ever in the history of higher education has one catchword made more headlines than ‘university rankings’*” (Hertig, 2016). Therefore, perhaps, the current study participants have been impressed by the news and media. For this reason, in their view, the number of a country’s institutions in the global league tables is an important criterion for assessing scientific leadership. On the other hand, it seems the concept of scientific leadership is more a political and propaganda concept. Therefore, the relevant indicators (especially those covered in the news and media) should measure it; indicators such as the league tables are more focused on media than other areas.

On the other hand, according to the experts' viewpoints, the role of indicators in the "academic journals" dimension is very important for measuring scientific leadership. Academic journals are the primary sources for information dissemination and important media for science communication. They play a key role in publishing the latest research findings and disseminating the articles covering the current developments in various fields of science" (Thanuskodi, 2012). However, published research findings in academic journals are not necessarily authored by domestic researchers and might come from other countries. The quantity and quality of the academic journals of a certain country do not represent that country's scientific leadership level.

Conclusion

Collecting data for the indicators identified in the current study's proposed framework makes it possible to compare different countries with each other and measure their scientific leadership. It may not be possible to measure the scientific leadership of a country in general, but its leadership in various areas can be measured based on the proposed indicators. The findings of this study can give policymakers a more comprehensive and accurate view of the concept of scientific leadership and assist them in various planning and research policies. In addition, the proposed framework is the basis for future research seeking to assess scientific leadership quantitatively.

Limitations and Recommendations

The first and critical limitation of this research was that the concept of scientific leadership had been clearly defined, neither in Iran nor in the world, and experts with different experiences and backgrounds have different definitions of this concept. Hence, their answers depended on their mental construction in defining this concept. In addition, news and mass media reports may have influenced the expert mentality about the concept of scientific leadership.

The results of this study are limited to quantitative indicators and metrics introduced and published by various institutions. Hence, the proposed framework does not include a qualitative indicator. The proposed framework is only used to quantitatively assess the scientific leadership, while other areas can also be considered. Future research that focuses solely on the qualitative aspects of scientific leadership may be helpful in this regard.

Conducting research - perhaps through grounded theory - is useful for conceptualizing scientific leadership and clarifying its various aspects. The conceptualization of scientific leadership can be more effective in defining its multiple dimensions. Based on previous works and experiences obtained in this study, the definition and dimensions of scientific leadership depend on the context. Perhaps conducting research similar to the current study in other countries will provide a more comprehensive view of scientific leadership.

In the current study, policy documents, previous works, and the views of a limited number of experts were analyzed, but in other studies, different sources of information can be examined and reconciled with the results of this study. For example, examining the dimensions of scientific leadership by surveying and gathering the views of larger communities can be helpful. The study focused on indicators and metrics that had previously been introduced in academic literature or had been published by different institutions. Therefore, the results of this study are limited to identified indicators and metrics that already exist. However, in future research, a panel of experts can identify indicators for measuring scientific leadership that did not exist before. This panel can provide a more efficient framework for assessing academic authority if its members' diversity is considered.

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