Research on the Generation of Safety Culture and the Practical Investment Directions in the Chinese Chemical Industry[1]

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Abstract: In order to facilitate and advance safety management within the chemical industry and to further improve the theoretical foundation of safety culture in the chemical industry; this study systematically investigates the generation of safety culture and the practical investment directions in the chemical industry using methods of logical analysis and literature analysis. Firstly, a definition of safety culture generation in the chemical industry is proposed. Based on this definition, six factors influencing safety culture generation are identified: chemical industry employees, safety production needs, safety hazards, empirical methods, response results, and employees' safety assurance capabilities. Furthermore, five approaches and two motivations of safety culture generation in the chemical industry are delineated. By sifting through and analyzing pertinent literature, this study sums up four kinds of practice forms and investment directions: scientific theory research, scientific technology application, formulate rules and regulations, and scientific popularization. The findings reveal that the process of safety culture generation in the chemical industry can be categorized into three stages: demand generation, ability/awareness generation, and system generation. The generation mechanisms encompass six factors, five approaches, two motivations, and four practical forms and investment directions.

Keywords: Safety culture; generation mechanism; investment directions; financial management; The chemical industry

1   Introduction

With the rapid development of the social economy, the chemical industry has gradually become a cornerstone of China's national economy.[1] However, the continuous development of the chemical industry has also brought enormous pressure to safety production.[2][3] In recent years, there have been multiple severe production safety accidents in the chemical industry, such as "Tianjin Port 8·12 Explosion" and "Jiangsu 3·21 Explosion," which have caused enormous casualties and economic losses and have caused various negative impacts on

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society. As a result, the safety production work in the chemical industry has received high attention from the government and all sectors of society. Research has indicated that employee unsafe behavior constitutes the primary cause of chemical accidents in China.[4] Developing safety culture within enterprises effectively improves employee unsafe behavior and enhances safety management.[5] However, there is currently a lack of research on safety culture in the Chinese chemical industry, and only a few safety management personnel in the chemical industry are actively involved in safety culture development initiatives, including promoting safety culture ideals and creating safety culture-related products. This absence of a research framework has resulted in a lack of theoretical underpinning for systematically establishing safety culture within the chemical industry.

In summary, this article aims to undertake in-depth research on the generation and practice of safety culture in the chemical industry based on the research path of "generation of safety culture - generation of industry safety culture - practice of safety culture," explore more suitable ways and motivations for the generation of safety culture in the chemical industry, and propose more targeted practical methods and investment direction to improve further the academic theory of safety culture in the chemical industry.[6]

2 Factors Influencing the Generation of Safety Culture in the Chemical Industry

2.1 Definition of safety culture generation in the chemical industry

Compared to the various interpretations of "safety culture" in academic research, this article agrees that the term "safety culture" first appeared in the accident report of the International Nuclear Safety Advisory Group (INSAG), which confirms that the purpose of "safety culture" is to explore the causes of accidents and preventive measures.[7] With this concept firmly established, research on generating safety culture in the chemical industry gained a clear direction. Firstly, the term 'generation' is interpreted as 'growing, shaping, expanding, and nurturing' in modern Chinese dictionaries.[8] Therefore, the generation of safety culture includes two meanings: the formation and development of safety culture in a specific environment. This underscores the foundational basis of research on safety culture theory. Building upon this foundation, when we further examine the term "development," it becomes evident that the generation of safety culture also involves innovation and expansion of safety culture. Based on the above logical analysis, combined with previous definitions of safety culture generation and the characteristics of the chemical industry, the generation of safety culture in the chemical industry is defined as measures (including empirical methods and response results) that have been taken to address safety hazards in the working environment to meet the safety needs of employees in the chemical industry, as well as the development of safety assurance capabilities during the summary and implementation process.[6]

2.2 Determining the factors in the generation of chemical safety culture

Based on literature research and the definition of safety culture generation in the chemical industry presented in this article, the safety culture in the chemical industry is divided into six factors: employees in the chemical industry, safety production needs, safety hazards, empirical methods, response results, and the safety assurance capabilities of employees. The

development relationship between the six factors is shown in Figure 1, and the connotations and theoretical basis of each factor are introduced as follows:

Taking the 24Model as an example, the model clearly states that the "unsafe state of object" is the direct cause of the accident, but how to treat it is the result of the personal habitual behavior of the accident initiator, namely "human unsafe behavior."[9][10] Wang Wei conducted a more in-depth analysis of the 24Model and proposed that "human unsafe behavior" includes not only the accident initiator (frontline staff) but also relevant management personnel at all levels within the organization.[11] From this, it can be seen that the direct cause of the accident can be related to employees at each level. This article believes that in safety culture generation, "the unsafe state of object" is the root cause of the emergence of safety culture and then develops into the demand generation stage of safety culture. This stage comprises employees, safety production needs and safety hazards. The motivation comes from avoiding property losses and casualties caused by accidents, and there are two factors: internal motivation and external mechanism. The internal motivation mainly comes from the stimulation of hazards, while the external mechanism is reflected in various levels of society.[12] The response results and empirical methods to safety hazards are formed through multiple communication channels, after a long-term summary, mature empirical methods will be fed back to the response results, forming more mature technical means. This stage is the safety culture's ability/awareness generation stage, an essential manifestation of culture generation function.[12] After experiencing the ability/awareness generation stage, the ultimate expression is the core principles of safety culture, which have plasticity and extensibility.[13] It is a constantly evolving process, reflected in various fields of the man-machine-environment-management system, ultimately forming horizontal development after vertical development, and forming various levels of safety assurance capabilities.[14] This process is the system generation stage of safety culture, and the system will continuously develop and improve according to the core principles of safety culture, which is a reflection of the generation of safety culture.[15]
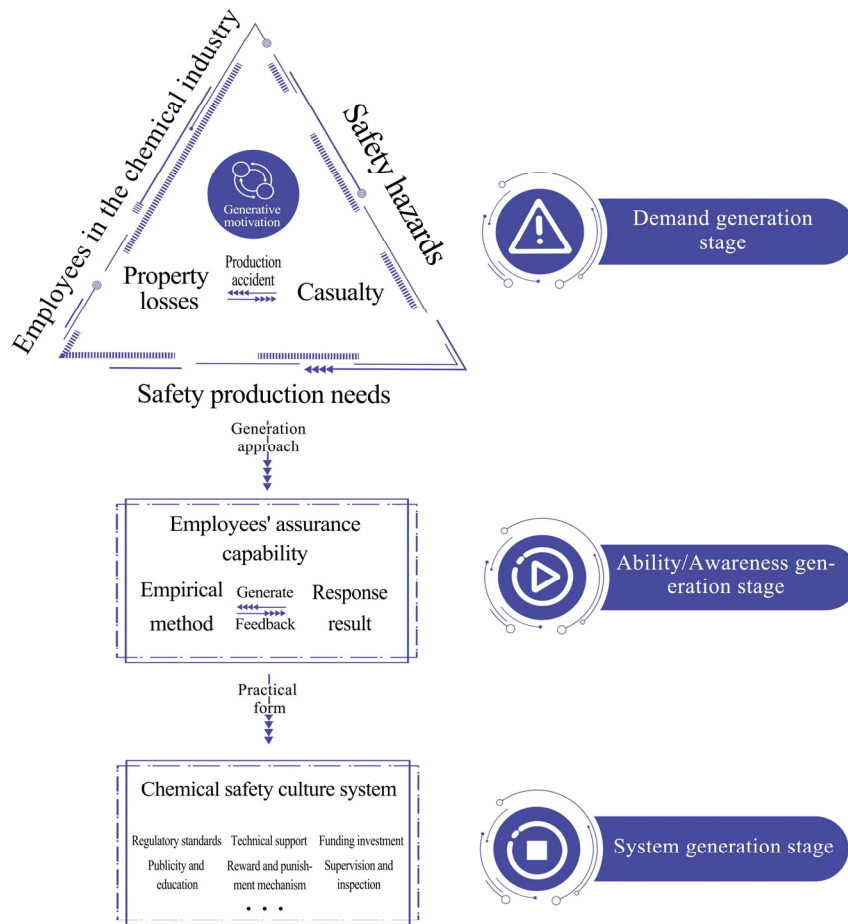
Figure 1 The interrelationships between factors in the generation of safety culture in the chemical industry

3 Approaches to the Generation of Safety Culture in the Chemical Industry

By analyzing the interrelationships between factors in the generation of safety culture, it can be concluded that the primary form of safety culture in the chemical industry needs to be obtained through the mutual transformation of empirical methods and response results. Different empirical methods will produce different response results, and the response results obtained by different transformation way are also different. This evolution has led to different safety cultures in the chemical industry. According to the classification of research on the

generation approaches of safety culture in China, combined with the characteristics of the chemical industry, the generation approaches of safety culture in the chemical industry are divided into ability, awareness, and ability/awareness types. The response methods include five types: united behavior, practical behavior, rational behavior, self-discipline behavior, and impression behavior.[6] The specific explanations are shown in Table 1. These five methods have generated the current safety culture in the chemical industry, providing varying degrees of safety production assurance for chemical industry employees in various aspects.

Table 1 - Approaches to the Generation of Safety Culture in the Chemical Industry

Approaches	Response methods	Generation type	Explanation
ability/awareness type	united behavior	enterprise systematic safety culture	Employees may face various hazards when working, but their individual protective ability is limited. To better deal with hazards, the work team needs to unite and leverage their strengths to compensate for the lack of individual protective ability, called "united behavior." In the collaboration process, there has been a division of labor and responsibility, and employees have gradually become dependent on collaboration behavior, forming safety culture for the enterprise.
ability type	practical behavior	material safety culture	There are various hazards in the workplace in the chemical industry. During the work process, employees equip safety assurance equipment and tools and create safe work processes (such as protective equipment for hazardous operations and work process design), which reflects the employees' awareness and ability to protect against hazards.
	rational behavior	scientific safety culture	Employees in the chemical industry will face various hazards during their work and actively consider solutions to identify the patterns of hazards (such as studying the characteristics of employee violations and providing targeted training), which is called "rational behavior." In rational behavior, a scientific safety culture is summarized using interdisciplinary scientific evidence to discover patterns.
awareness type	self-discipline behavior	regulation, behavior safety culture	Employees face many hazards that cannot be avoided by relying on technical methods and equipment. They need to change their mindset and improve their behavior to prevent accidents, called "self-discipline behavior." Self-discipline behavior ultimately manifests as laws and regulations, management systems, and behavioral norms, thereby reflecting the self-discipline ability of employees.
	impression behavior	art, scientific popularization safety culture	Many employees have never experienced a safety accident, so enterprises will summarize and learn from past cases, display various artistic works created through artistic processing and scientific popularization to employees (such as promotional posters, film and television works, and literary creations), to strengthen employees' understanding of hazards, accidents, and response methods, and

establish confidence in overcoming hazards. This kind
of behavior is called "impression behavior".

4 Motivation of Safety Culture Generation in the Chemical Industry

Both internal motivation and external motivation drive the generation of safety culture. The primary manifestation of internal motivation is the power formed by chemical enterprises and employees within the organization, including active and passive generations. One is voluntary compliance by employees, and the other is passive generation by employees under organizational management.[16] Therefore, internal motivation is divided into spontaneous type and management type. The external motivation mainly comes from the external factors of the enterprise. One is the safety production responsibility of the organization and employees, which is passively generated in the social environment.[17]The other is the supervision by various sectors of society. Due to employees actively exposing organizational behavior, active and passive generations coexist.[18] Therefore, external motivation is divided into responsibility and supervision, as shown in Table 2.[19]

Table 2 Motivation of Safety Culture Generation in the Chemical Industry

Motivation	Type	Meaning	Reasons	Note
internal motivation	spontaneous type	This motivation is mainly derived from the employees' safety culture. It belongs to people's basic needs for safety and is not related to the constraints of managers on their economy and interests. This motivation is proactive for employees.	① With the development of society, the safety quality of employees gradually improves; ② The improvement of safety needs among employees in the process of social civilization; ③ Measures to prevent and control hazards are constantly improving, and so on.	This motivation, directly and indirectly, encourages employees to gradually generate safety awareness, improve safety knowledge and skills, and ultimately generate safety culture during production.
	management type	This motivation mainly comes from the external influence exerted by managers on employees, which is passive for employees.	① Safety accidents in the organization; ② Economic losses lead to organizational safety	At present, the construction of safety culture in the Chinese chemical industry is mainly carried out in accordance with the "Guidelines for the Construction of Enterprise Safety Culture" and the

			development needs; ③ Learning and drawing on advanced safety culture, and so on.	"Evaluation Criteria for the Construction of Enterprise Safety Culture". The chemical industry has not yet introduced relevant standards, but the construction of enterprise safety culture is involved in various safety management regulations.[20][21]
external motivation	responsibility type	This motivation mainly comes from government regulation and industry supervision, which is influenced by industry and regulatory decisions and is passive for organizations and employees.	① Negligent behavior in chemical accidents; ② New requirements for improving safety management level; ③ The requirements put forward by industry guild for production and operation units and chemical enterprises;	The generation of safety culture in the chemical industry is an organizational responsibility. This motivation has promoted a more diverse safety culture, which supports active generation within the organization and the input of external culture.
	supervision type	This motivation mainly comes from the supervision of various sectors of society and is influenced by the media and the public's attention to the industry and enterprises. At the same time, organizations and employees can also use attention to enhance the influence of safety culture.	① Social losses caused by chemical accidents; ② The media's attention to industry and enterprises; ③ Exposure of employees to organizational and personal behavior;	With the enhancement of social supervision capabilities, the supervisory motivation behind the generation of safety culture in the chemical industry is gradually being valued.

The spontaneous motivation reflects employees' initiative in generating safety culture. The chemical industry employees must operate high-risk equipment and instruments, transport and manage many chemical products, and the working environment is hazardous. The willingness of employees to learn and influence each other to generate safety culture is exceptionally high. Spontaneous motivation spreads from individual to organization, a bottom-up generation mode. On the contrary, the management type of motivation emphasizes the role of managers in shaping safety culture. Due to external influences and losses caused by their accidents,

organizations must shape their own safety culture according to safety production requirements.[20][21] The management type of motivation is a top-down generative mode that directly affects individuals through organizational development.

In China, the chemical industry belongs to high-risk industries and faces strict safety production supervision.[17] Unlike previous strong regulatory models, the current focus of government safety supervision has shifted to emphasizing the implementation of the primary responsibility of enterprises for their safety production. Safety management has become the task of enterprises themselves, and they are constantly subject to government and industry supervision, resulting in a responsibility type of motivation.[22] The supervision type of motivation refers to the constant public opinion supervision of chemical enterprises by the media, the public, and even various sectors of society. The scale of China's chemical industry is already quite large, and there is enormous competition among chemical enterprises. In today's era, where the government emphasizes high-quality development, factors such as product quality, corporate image, and corporate safety level all affect the production and operation of chemical enterprises. Once an accident occurs, the impact on the corporate image is enormous, which may lead to the complete loss of market competitiveness for enterprises, therefore, the supervision type of motivation significantly impacts the safety culture of chemical enterprises.

In the chemical industry, whether at the individual or organizational level, the two types of culture generation motivation complement each other, ultimately providing a continuous source of impetus for collectively driving culture development within the chemical industry.

5 Practical Forms of Safety Culture Generation and Investment Directions in the Chemical Industry

The model's construction shows that the ultimate practice of safety culture generation in the chemical industry is building a chemical safety culture system, which enhances safety assurance capabilities. In the system, all types of practical forms are included. This article uses CiteSpace to conduct literature searches on the Chinese core journals published by CNKI from 2000 to 2023, using "safety culture" and various high-risk industries as keywords.[23] The CiteSpace application process is shown in Figure 2. The main formulas can be found in (1), (2), and (3). One hundred fifty-two articles were retrieved, the results obtained through keyword co-occurrence analysis are shown in Figure 3. Based on the analysis results, this article analyzes four essential forms of chemical safety culture system.
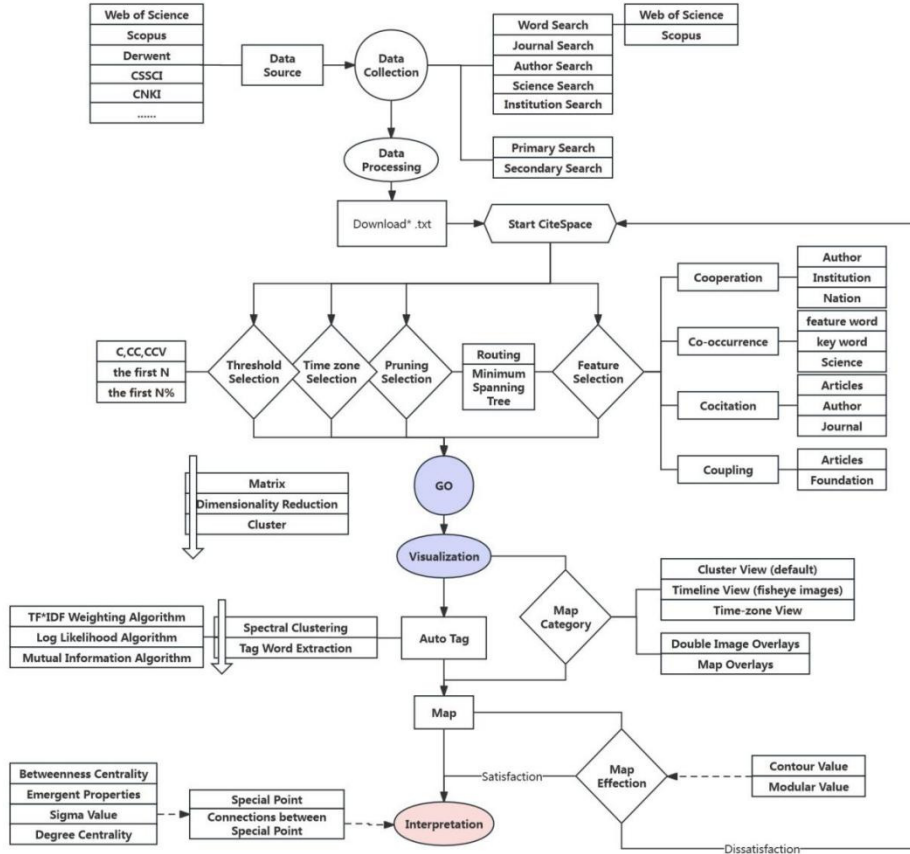
Figure 2 CiteSpace application process

Betweenness Centrality:Node betweenness refers to the number of shortest paths through nodes in a network.The formula for calculating the betweenness centrality of a node is as follows:

$$BC_i = \sum_{s \neq i \neq t} \frac{n_{st}^i}{g_{st}} \quad (1)$$

n_{st}^i indicates the number of paths that pass through node i and are the shortest path.

g_{st} shows the number of shortest paths connecting s and t.

Degree Centrality: It is the most direct metric for characterizing node centrality in network analysis. The greater the degree of a node, the higher its degree centrality, and the more important it is in the network.

$$\mathrm{DC_i} = \frac{k_i}{N-1} \quad (2)$$

k_i Indicates the number of existing edges connected to node i.

N-1 The number of edges that represent nodes connected to other nodes.

Sigma value: Sigma value is a composite of two indicators: Betweenness centrality and burstness. It is used to identify innovative literature and can be used to identify innovative themes.

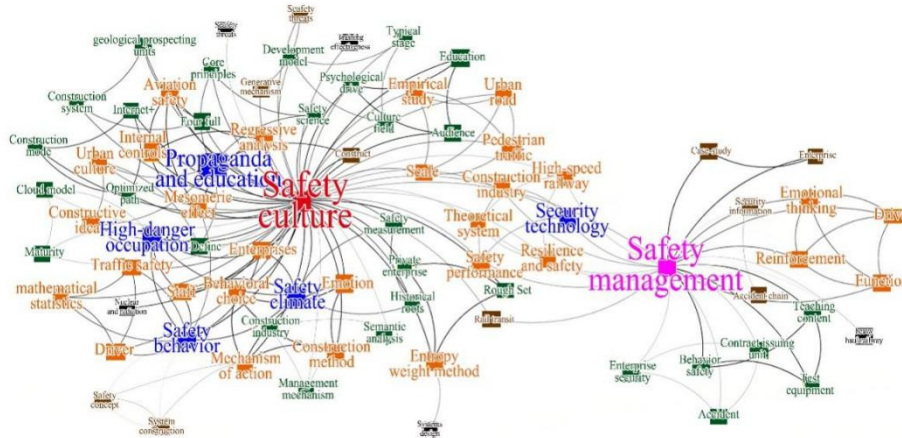$$\text{Sigma value} = (\text{centrality}+1)^{\text{burstness}} \quad (3)$$

Figure 3 Analyze results using CiteSpace

5.1 Scientific theory research

According to the classification standards of Chinese disciplines, safety culture is a sub-discipline under the "safety social science".[24] Although there are currently differences in understanding of "safety culture", the disciplinary division indirectly proves that the development of safety culture is closely related to social development. The generation of safety culture relies on scientific theory, and only by improving the level of scientific theory can the safety culture be improved.[25] In the current practical process of generating safety culture in the chemical industry, scientific theory is dominant in finding scientific measures to address hazards. This kind of scientific theoretical practice needs to invest funds to summarize and apply a large amount of interdisciplinary scientific theoretical knowledge, and its output is mostly in the form of written works and publications.

5.2 Scientific technology application

Based on scientific theory, the following practical form and investment direction is the application of scientific technology, and the focus should be on investing funds to ensure the scientific technology products in the chemical industry's production process.

For example, the IoT-based equipment detection and control system widely used in the chemical industry currently utilizes various sensors and control units to monitor and alarm the equipment status remotely and timely grasp and control equipment risks. This detection system integrates many interdisciplinary scientific technologies, such as electronic information technology, chemical engineering, and safety science, and is a fundamental manifestation of safety culture in the chemical industry.[26]

5.3 Formulate rules and regulations

In the chemical industry, safety production regulations are the foundation for the construction of safety culture, often appearing in rules, regulations, and standards of enterprises and industries. Taking the safety management of chemical enterprises as an example, in order to further standardize the safety management of chemical enterprises, the Ministry of Emergency Management of the People's Republic of China has issued the "Guidelines for chemical process safety management" (AQ/T 3034-2022), replacing the "Guidelines for process safety management of petrochemical corporation" (AQ/T 3034-2010) and implementing it from April 1, 2023.[27][28] Based on the current situation of chemical process safety management in China, this standard integrates international advanced process safety management concepts and best practice experience, as well as relevant safety production technical requirements, striving to be close to the actual management of enterprises and form a chemical process safety management system suitable for China's national conditions. Various investment guarantees in the formulation of rules and regulations can lay a foundation for the generation of safety culture in the chemical industry, and provide a guarantee for the development of existing safety culture.

5.4 Scientific popularization

Based on scientific theory, technological support, and regulatory basis, the popularization of safety culture in the chemical industry is imperative. Scientific popularization refers to the easy-to-understand processing of various safety knowledge, allowing employees to accept the content that needs to be mastered and followed during the operation process in a popular form.[29] This safety culture practice and investment direction is mainly manifested in posters, display boards, cultural and creative products, film and television works, WeChat official account articles, etc. Scientific popularization can positively impact employees and effectively showcase and promote the organization's safety culture experience and image.[30]

Through the analysis of four practical forms and investment directions, the current developmental progression of safety culture generation and investment in the chemical industry can be summarized as follows: "scientific theory-scientific technology- regulations-popularization". The changes in scientific technology application are the most rapid among them. Due to the involvement of many interdisciplinary manifestations of scientific technology, it directly affects the establishment of scientific theories and regulations, and even

affects the methods of scientific popularization, therefore, the application of scientific technology application is the key direction of investment.

6   Conclusion

Through research on the generation and investment directions of safety culture in the chemical industry, the following conclusions are drawn.

1)The six factors involved in the generation of safety culture in the chemical industry are safety production needs, safety hazards, chemical industry employees, empirical methods, response results, and employees' safety assurance capabilities. The generation of safety culture in the chemical industry results from the combined action of these six factors.

2)There are five approaches to generating safety culture in the chemical industry: united type, practical type, rational type, self-discipline type, and impression type. Generation motivation includes four types: spontaneous type, management type, responsibility type, and supervision type. There are four forms of practice and investment directions: scientific theory research, scientific technology application, formulate rules and regulations, and scientific popularization.

3)The empirical methods and response results in the generation factors of safety culture in the chemical industry are mutually transformed, and a new safety culture will be generated during the transformation process. The progress of scientific theory and technology in practical forms will also affect the practical form of safety culture generation in the chemical industry.

4) In the process of chemical industry safety culture practice, the application of scientific technology is the key direction of investment, and the application of scientific technology will directly affect the establishment of scientific theories and rules and regulations, and even affect the ways and methods scientific popularization.

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