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Exploring the behavioral mechanisms of Chinese scientists' public engagement with science based on an integrative model

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Abstract

Based on self-determination theory and the theory of planned behavior, this study explored the predictors and behavioral mechanisms associated with Chinese scientists' public engagement with science. The results indicated that scientists' participation was associated with their levels of perceived autonomy, their attitudes toward participation and the media, subjective norms, perceived policies, their own efficacy, specific facilitating conditions, habits related to communication, and their willingness to engage. Under different levels of autonomy, these indicators had different association with scientists' willingness to engage and their reported participation in science communication activities. As levels of controlled motivation (or external requirement to communicate) increased, more negative effects related to willingness to participate or self-reported participation were identified, and amotivation (a lack of motivation) had a direct negative association with participation. The theoretical and practical implications of these findings are discussed.

Keywords Public engagement with science and technology; Science and media; Science communication: theory and models

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Scientists are usually encouraged to participate in science communication by the scientific community and related organizations [Copple et al., 2020; Ho, Goh & Leung, 2022; Sharon & Baram-Tsabari, 2020], as public engagement with science is considered important to bridge the gap between the scientific community and the public, and to increase public support and trust for scientific research and related endeavors [Greenwood & Riordan, 2001; Leshner, 2007]. Studies indicate that most scientists agree with the value of science communication and are willing to engage in it [Hvidtfelt Nielsen, Kjaer & Dahlgaard, 2007; Jin, Wu, Chu, Lin & Zhang, 2018], but their actual participation rate is low [Bauer & Jensen, 2011]. In China, a survey showed that 73.5% of scientists had not participated in any media-related science communication in the past year [Jia, Shi & Wang, 2018]. Accordingly, there might be a discrepancy between scientists' willingness to participate in communication activities and their actual participation behavior. Many factors, such as motivations, social norms, and public opinions, could affect scientists' participation [Chen, Zhang & Jin, 2023]. Those factors that have significant impacts on behavior should be given more attention, as they may have a decisive role in scientists' engagement in science communication. Determining the behavioral mechanisms of scientists' involvement in science communication and identifying the key indicators within this mechanism are therefore necessary.

Research on the mechanisms influencing scientists' behavior related to science communication has mainly been conducted in Western contexts. Limited systematic studies have been conducted in China, which has a different science communication environment and is home to the largest population of scientific researchers in the world [Zhang, 2015; Chen et al., 2023]. The present study aimed to identify the mechanisms influencing scientists' behaviour related to science communication. It draws on the motivation–attitude–behavior model, based on the theory of planned behavior and self-determination theory, as well as findings from prior interview research with Chinese scientists [Li & Zhang, 2023] to develop a survey instrument that was applied to scientists living and working in the mainland of China. The paper investigates the motivations, attitudes, norms, and relevant indicators of scientists' participation behaviour, outlines the essential predictors in the process of generating this behavior, and provides suggestions for future research and practice.

Literature review

In the 1930s, British professor of physics and science communication enthusiast, J. D. Bernal argued that the target audience of scientific communication should include not only scientists, researchers, and other professionals but also the public [Bernal, 1939]. With the progress of science and technology, the growing demand for and the importance of scientific knowledge to the public, and the promotion of science activities by governments and other related institutions, science communication models progressed mainly from the popularization of science to its public understanding and, finally, to public engagement with science; and all forms of science communication coexist and may, in fact, rely on each other [Metcalfe, 2019]. Because of the late development of this field in China, the integration of traditional and new media, and other related reasons, these three patterns and stages of scientific communication currently also coexist in the practice of science communication in the country [Liu, 2009].

Science communication is defined as "the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science: awareness, enjoyment, interest, opinion-forming, and understanding" [Burns, O'Connor & Stocklmayer, 2003, p. 183]. For scientists, there are five main forms of engagement: daily participation, public dialogue, deliberation, knowledge co-production, and university-led cooperative activities [AAAS, 2016; Nisbet & Markowitz, 2015; Storksdieck, Stylinski & Bailey, 2016; Peterman, Robertson Evia, Cloyd & Besley, 2017], The process of targeted or meaningful knowledge sharing by scientists, researchers, and professionals through certain channels, such as social media and offline presentations, can be called science communication. Although scientists in China have been encouraged to engage in various forms of science communication by their employing institutions, science communities, and governments, they remain largely *unenthusiastic* toward these activities [Zhang, 2015]. Many factors could account for this lack of enthusiasm. However, relatively few studies in China have investigated scientists' motivations to communicate from a psychological perspective, nor have they systematically investigated the mechanisms underpinning scientists' behaviour in relation to science communication.

Whether scientists participate in science communication is related to scientists' complex cognitive and psychological processes and to various internal and external predictors. Based on different research perspectives, numerous factors have been investigated in the literature. With the exclusion of demographic indicators and previous experiences, the factors that influence scientists' intentions to participate and their actual participation behavior can be generalized into two main categories. The first category is made up of social and psychological variables, such as attitudes, subjective norms, and perceived behavioral control (PBC), which are conceptualized in the theory of planned behavior [Chen et al., 2023]. In this category, some studies have discussed scientists' intentions within the framework of the theory of planned behavior [e.g. Besley & Dudo, 2017; Besley, Dudo, Yuan & Lawrence, 2018; Poliakoff & Webb, 2007], whereas others have examined the variables separately [e.g., Bentley & Kyvik, 2011; Chen et al., 2023; Martín-Sempere, Garzón-García & Rey-Rocha, 2008; Marcinkowski, Kohring, Fürst & Friedrichsmeier, 2014; Peters et al., 2008; Tiffany, Hautea, Besley, Newman & Dudo, 2022]. The second category consists of rewards, goals, and motivations [e.g., Burchell, 2015; Dudo, 2013; Dunwoody, Brossard & Dudo, 2009; Martín-Sempere et al., 2008], which could be considered the psychological drivers of scientists' participation in science communication. Studies have shown that these rewards and motivations can be divided into intrinsic and extrinsic aspects, and they have different effects and the mechanisms associated with scientists' willingness and actual participation in public outreach in different contexts [Dunwoody et al., 2009]. Then, what are the relationships between these two sets of variables, and could they comprise a new model or perspective to understand scientists' willingness to participate and the behavioral mechanisms associated with their participation in science communication more comprehensively? These issues need to be further investigated and discussed.

The theory of planned behavior, scientists' willingness, and participation

According to Ajzen, the theory of planned behavior posits that intentions have positive impacts on future behaviors and it "postulates three conceptually independent determinants of intention": attitude, subjective norms, and perceived behavioral control [Ajzen, 1991, p. 188]. *Attitude* refers to individuals' pre-determined positions on the performance of a certain behavior, including whether it is important or valuable [Ajzen, 1991]. In the practice of science communication, scientists usually interact with the media and the public; therefore, aside from their attitudes toward science communication itself, their attitudes toward the media and their audiences should be considered [Jin et al., 2018].

Attitude toward participation has been found to have a positive association with the willingness to participate [Poliakoff & Webb, 2007], but this attitude may not be consistent with the behavior shown by scientists [Jin et al., 2018]. According to the theory of planned behavior, willingness is associated with behavior, and attitude is positively related to willingness. Thus, what happens in the process and the behavioral mechanisms of scientific communication needs further inquiry. As the media are important participants in science communication, scientists should also understand the media and their ways of operating [Dunwoody et al., 2009; Tsfati, Cohen & Gunther, 2011]. The media influence if and how scientists participate in science communication and how they view their participation [Brossard, 2009]. Studies suggest that the attitudes and perceptions of journalists are associated with scientists' willingness to participate or how they behave in relation to science communication [Besley et al., 2018; Lo & Peters, 2015; Peters et al., 2008]. Scientists can stop actively participating in science communication if journalists are unable to clearly articulate their research, views, and/or conclusions, meaning that scientists are misunderstood by the public [Ashwell, 2016; Dunwoody & Ryan, 1985; Maillé, Saint-Charles & Lucotte, 2010]. Peters [1995] attribute these misunderstandings to journalists and scientists coming from two different cultures. Some scientists also believe that science communication should be the job of journalists and other professionals or institutions, rather than scientists [Bentley & Kyvik, 2011].

Scientists also need to analyze the target groups and their varied needs in different media and contexts as the audience is the ultimate recipient of information of the communication activities, and then formulate an appropriate strategy before communicating. For example, the deficit model claims that audiences generally lack relevant scientific knowledge, so science communication is needed for this purpose; other models indicate that the needs of the audience should be given attention [Weigold, 2001; AAAS, 2016]. In the four stages of the dissemination of scientific knowledge [Bucchi, 1996] and the five types of activities of science communication mentioned above, the audiences and their needs are different, so the strategies for reaching out to them should also be different.

Scientists' perceptions of the audience depend on the composition, attitudes, and scientific literacy of the latter [Bentley & Kyvik, 2011], such as whether the audience can appreciate research [Poliakoff & Webb, 2007; Rainie, Funk & Anderson, 2015], understand and accept what is communicated [Maillé et al., 2010], trust the researcher involved [Fiske & Dupree, 2014; Besley et al., 2018], believe in whether the researcher holds a fair perspective [Besley & McComas, 2015; Colquitt, Greenberg & Zapata-Phelan, 2005], and engage in interactions. Investigation of the attitudes of Chinese scientists toward their audiences and the relationship of these attitudes to their willingness to communicate and their actual participation, is needed. Based on this investigation of the behavioral mechanisms of science communication, the following research question is proposed:

RQ1: How do the three types of attitudes (toward science communication, toward the media and toward audiences) associate with scientists' willingness to participate in science communication?

Subjective norms refer to the "perceived social pressure to perform or not to perform [a] behavior" [Ajzen, 1991, p. 188] and to beliefs about important others' attitudes on one's action or behavior [Rivis & Sheeran, 2003]. Martín-Sempere et al. [2008] found that scientists' perceived attitudes toward people who are significant to them, including the attitudes of their friends and colleagues, impacted their participation in science communication. Different norms also have different effects on scientists' willingness to participate in science communication [Chen et al., 2023]. However, whether and how subjective norms associate with the general behavioral mechanisms informing Chinese scientists' participation in science communication have been relatively less explored.

Scientists also form perceptions about the culture and norms of their scientific communities [Besley, 2015; Godin & Gingras, 2000] and evaluate these professional situations before they participate in science communication. Different disciplines may have different views and cultures regarding engagement in science communication. As the content of some subjects is relatively abstract and not suitable for dissemination, scientific content that can be presented in a better form is more popular with the public. Moreover, the Sagan effect — participating in science communication might result in a negative reputation and normative sanctions [Chen et al., 2023; Ecklund, James & Lincoln, 2012; Entradas & Bauer, 2019; Johnson, Ecklund & Lincoln, 2014] within the discipline and community — may also have effects on participation and willingness.

Additionally, scientists' perceptions of leadership, government policies, and related factors can affect their participation in science communication [Marcinkowski et al., 2014; Mo, Peng & Gan, 2017; Poliakoff & Webb, 2007] as subjective norms. Bentley and Kyvik [2011] stated that institutional factors are essential to scientists' participation, and the government's emphasis and related policies on science popularization could encourage more scientists and related institutions to participate.

Generally, based on the theory of planned behavior and relevant studies, the subjective norms informing scientists' science communication efforts mainly consist of significant others' attitudes, such as those of family members and colleagues. In practice, they can also be related to a discipline's culture (norms within a discipline/community), perceived public opinions (perceived views of audiences), and policy perceptions (norms in scientists' affiliations and the government), which may have a relationship with scientists' willingness and participation. Exploring how these factors associate with scientists' willingness to participate is necessary. In this regard, the following research question is proposed:

RQ2: How do subjective norms and related views associate with scientists' willingness to participate in science communication?

Perceived behavioral control refers to "the perceived ease or difficulty of performing [a] behavior", which is closely associated with Bandura's concept of self-efficacy and with individuals' intentions and behaviors [Ajzen, 1991]. Studies have shown that scientists' participation in science communication activities is related to their level of efficacy [Besley, 2015; Besley et al., 2018], such as whether they can convey information clearly, and to their media literacy and confidence levels [Gascoigne & Metcalfe, 1997].

The definition of perceived behavioral control indicates that scientists' participation in science communication may also be related to *facilitating conditions*, which refer to individuals' perceived favorable conditions that encourage them to perform an action [Thompson, Higgins & Howell, 1991], such as opportunities to participate. Opportunity has an important influence on behavior [Phan, Wong & Wang, 2002], and scientists report a lack of opportunities as one of the most influential factors affecting their participation [Bentley & Kyvik, 2011; Gascoigne & Metcalfe, 1997]. The development of the internet and social media has made it easier for scientists to obtain opportunities to participate in science communication. A survey of American-based scientists connected with the American Association for the Advancement of Science (AAAS), found that nearly half of them published science-related content through blogs [Rainie et al., 2015]. Furthermore, most scientists consider whether they have time to participate before they actually do so, and a lack of time is cited by scientists as a major reason for not participating [Bentley & Kyvik, 2011; Besley et al., 2018; Poliakoff & Webb, 2007].

Habits could also have a significant influence on future behavior and on the decision-making process [Conner & Armitage, 1998; Hagger & Chatzisarantis, 2009]. It has been suggested that there may be a correlation between the low motivation of chemistry and physics scholars to participate in science communication and their research habits [Besley, Oh & Nisbet, 2013]. However, whether and to what extent perceived behavioural control and related factors associate with scientists' willingness and actual behavior in regards to science communication in the context of China require further investigation. Therefore, the following research question is posed:

RQ3: How does perceived behavioural control and related factors associate with scientists' willingness to participate in science communication and their actual participation?

The motivation–attitude–behavior model

Although the theory of planned behavior is widely used to analyze human's willingness and behavior, some researchers consider it insufficient to explain individual behavior and that it should be improved and combined with concepts drawn from self-determination theory because the theory of planned behaviour lacks fundamental factors, such as motivations [Chatzisarantis, Hagger & Smith, 2007; Hagger & Chatzisarantis, 2009]. Self-determination theory states that human beings can fulfill their needs by behaving in a self-determined cognitive way in which they comprehensively consider their needs, and motivations and the influencing factors [Deci & Ryan, 2015]. And it classifies individual motivations according to their degree of autonomy, from amotivation, controlled motivation to autonomous motivation, with different mechanisms, from motives to behavior.

In science communication studies, the relationship of the theory of planned behavior to scientists' willingness and participation behavior has been discussed in depth, while the motivation aspects of willingness and participation have seldom been systematically investigated. Scientists' motivations, such as meeting their values and responsibilities as scientists, acquiring and maintaining a certain reputation, sharing knowledge, and enjoying activities, are also important to their engagement. Besley, Newman, Dudo and Tiffany [2020] state that there has been little systematic research investigating scientists' goals and objectives, and the effects that their goals and objectives have on their participation in science communication. These researchers found that scientists "wanted decision-makers and others to support the use of science in policy and personal life", as well as seeking financial support for science [Besley et al., 2020, p. 865]. Goals and motivations are different, but they are closely related with each other to some extent. In the process of generating behavior, motivations typically arise before other factors, influence individuals' consideration of other factors, and promote behavior [Hagger & Chatzisarantis, 2009]. Therefore, based on willingness and the generation of behavior, related theories, and the literature, motivations should be considered when discussing scientists' participation intentions and behaviors. In studies of scientists' science communication behavior, motivations and theory of planned behavior factors are found to have association with scientists' willingness and behavior, but the relationship between them and their combined effects on willingness and behavior have rarely been examined.

In general, self-determination theory and the theory of planned behavior have similar theoretical foundations and orientations [Brooks et al., 2017]. To examine the diverse impacts on behavior, self-determination theory explores the causes and drivers of human behavior based on motivations and classifies them based on the level of autonomy involved. The theory of planned behavior explores internal and external factors and influencing processes. Combining the two theories may lead to a more comprehensive explanatory model [Hagger & Chatzisarantis, 2009; Standage, Duda & Ntoumanis, 2003]. According to previous studies, the *motivation–attitude–behavior model* is depicted in Figure 1 [Hagger & Chatzisarantis, 2009].

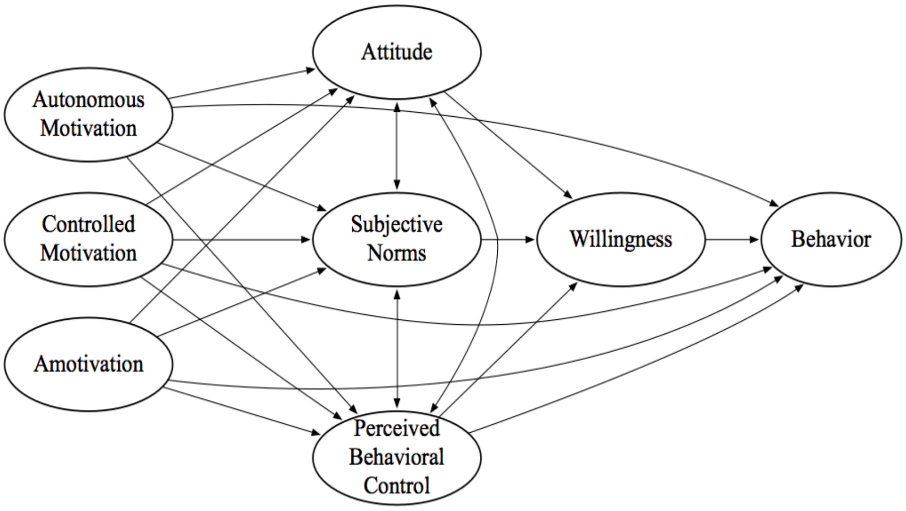

Figure 1. The motivation–attitude–behavior model.

Scientists' motivations, willingness, and participation

Self-determination theory classifies motivations into autonomous motivation, controlled motivation, and amotivation based on the levels of autonomy involved [Deci & Ryan, 2000]. Autonomous motivation, which indicates that people "act with a full sense of willingness and volition, wholly endorsing that which they are doing because they find it either interesting and enjoyable, or consistent with their deeply held, integrated values" [Deci & Ryan, 2015, p. 486], includes intrinsic motivation, integrated regulation motivation, and identified regulation motivation based on their different levels of autonomy, which are presumed to have positive effects on behavior [Deci & Ryan, 2015; Gagné & Deci, 2005].

Autonomous motivation, willingness, and participation

According to the definition of self-determination theory and the classification of motivations, intrinsic motivation, which has the highest level of autonomy that can account for scientists' engagement in science communication, consists of three aspects. The first is scientists' interest and enjoyment in engagement, which is one of the main motivations for younger scientists to participate [Martín-Sempere et al., 2008]. The second aspect is the sense of satisfaction, including the sense of achievement, self-realization, and recognition, with satisfaction being one of the most important factors [Martín-Sempere et al., 2008; Burchell, 2015]. The third aspect is the motivation to share knowledge for instinctual reasons (just wanting others to know). Some studies have found that letting others know about relevant knowledge or research is one factor affecting participation, and more than 40% of scientists in China consider it important to their participation [Mo et al., 2017]. These feelings from activities or motivations are related to the gratification of basic psychological needs (autonomy, competence, and relatedness) and positively affect willingness and behavior according to self-determination theory.

Integrated regulation motivation and identified regulation motivation refer to an individual's agreement about the value of doing something before they autonomously perform a certain behavior [Deci & Ryan, 2015; Gagné & Deci, 2005]. In scientists' public engagement, they can relate to the following dimensions of motivations. The first is the belief that participating in science communication is the responsibility of scientists. Jin et al. [2018] showed that most scholars and organizations believe that scientists have a responsibility to participate in science communication and to inform the public of the possible social impacts of and ethical conflicts in scientific research. Scientists' sense of responsibility has a direct impact on whether they will be involved in public engagement [Besley et al., 2013; Besley et al., 2018; Dudo, Kahlor, AbiGhannam, Lazard & Liang, 2014; Sharman & Howarth, 2017]. Moreover, Martín-Sempere et al. [2008] found that a sense of responsibility is a great motivation for scholars who are older or have a higher professional status.

The second concerns self-improvement motivations, including the improvement of one's knowledge, skills, and academic influence. Peters et al. [2008] showed that scientists may evaluate whether an activity has an impact on their academic stature before they participate.

The third dimension involves personal needs or rewards, including earning income, popularity, and network resources. Bledow [2013] considered that personal need is an essential motivation for behavior and that most motivations and behaviors are meant to meet needs. Studies have shown that the expected return from scientists' participation has a relationship with their participation [Bentley & Kyvik, 2011; Besley et al., 2013; Besley et al., 2018; Dunwoody et al., 2009; Marcinkowski et al., 2014], and so does whether there are opportunities for promotion or income increase [Gascoigne & Metcalfe, 1997]. Overall, scientists who feel that participating in science communication could have benefits are likelier to engage in it [Besley et al., 2013; Dudo et al., 2014]. To some extent, self-improvement motivations can also drive the fulfillment of personal needs.

According to the positive influence mechanism of autonomous motivation on behavior in self-determination theory, the higher the level of autonomy involved in a motivation, the higher the possibility that an individual will behave in a certain way. However, whether this rule could apply to scientists' participation in science communication is unclear. Based on the above discussion, this study proposes the following research question:

RQ4: How do autonomous motivations associate with scientists' willingness to participate in science communication and their actual participation?

Controlled motivations, willingness, and participation

Controlled motivations indicate that individuals act from pressure and compulsion rather than concurrence; in the motivation–behavior mechanism of self-determination theory, different controlled motivations may have different effects on behavior [Gagné & Deci, 2005]. According to the literature on science communication and self-determination theory, scientists' controlled motivations to participate in science communication rely on three elements, based on the control level involved.

The first element involves external incentives or rewards, such as benefits for employers and affiliations, and obtaining social and government support. Some scientists consider whether their participation in relevant communication activities will bring more support to individuals or organizations before they participate [Hallonsten, 2014]. The second element concerns external requirements, including work demands, the provision of research projects or funding, and the fulfillment of previous commitments. Some studies have suggested that funding is related to participation [Jensen, 2011; Marcinkowski et al., 2014]. However, Besley [2015] found that the impact of this indicator is insignificant in the U.S. Some funders require scientists who receive their funding to communicate their research to the public, which is a controlled motivation factor that may compel scientists to do so in the short term. If controlled motivation cannot be internalized into autonomous motivation, an individual's enthusiasm will gradually decrease, and the effect of controlled motivation may become negative in the long run. The third element relates to compulsory requirements (highest degree of control), including the orders of team leaders, and failed in scientific research and to find some related work. Amabile [1985] showed that both autonomous and controlled motivations have positive effects on the production of behavior in the short term, but controlled motivation results in negative feelings and effects on behavior in the long run. How controlled stimuli or motivations associate with scientists' behavioral mechanisms remains to be seen. Therefore, this study poses the following question:

RQ5: How do controlled motivations associate with scientists' willingness to participate in science communication and their actual participation?

Amotivation, willingness, and participation

The third category of motivation is *amotivation*, which can be understood as a lack of motivation. Deci and Ryan [2015] regarded amotivation as having negative impacts on behavior, such as never having the thought of doing something or not knowing why something should be done. Correspondingly, we might assume that in science communication, amotivation has a negative effect on scientists' willingness and participation. Thus, this study proposes the following research question:

RQ6: How does amotivation associate with scientists' willingness to participate in science communication and their actual participation?

Methods

Sample

Before identifying the respondents and distributing the survey, we interviewed 27 scientists and experts in science communication to discuss the indicators of their willingness to participate in science communication [Li & Zhang, 2023]. Then, we designed the final questionnaire items based on self-determination theory and the theory of planned behavior scales, related items in other studies, and the interviews. A seven-point Likert scale was used for the responses (with 1 = *very unlikely* to 7 = *very likely*).

A survey of Chinese scientists regarding their participation in science communication was conducted from January 28, 2019 to February 18, 2019. Survey invitations were sent via an online questionnaire survey platform (https://www.wjx.cn/). Only those who indicated that their occupation was a scientist/researcher in the questionnaire were asked to answer the questions. The system was set in such a way that a person with the same IP or device would not be able to complete the questionnaire for a second time to ensure the validity of the data collection process. A total of 300 questionnaires were deemed valid and completely answered by 151 males (50.3%) and 149 females (49.7%). Most of the respondents (278, 92.6%) were aged 26–45 years. Tables 1 and 2 show the descriptive statistics of the sample. The Cronbach's coefficients of the questionnaire items were all higher than .700, and the questionnaire had good internal consistency and high reliability.

Measurements

Motivations were measured using the self-determination theory scale [Deci, Hodges, Pierson & Tomassone, 1992; Ryan & Connell, 1989], the interview questions, and items from related research [Besley et al., 2018; Dudo, 2013; Dunwoody et al., 2009; Gascoigne & Metcalfe, 1997; Jensen, 2011; Jia et al., 2018; Martín-Sempere et al., 2008; Mo et al., 2017], which included 11 items for autonomous motivation, 8 items for controlled motivation, and 3 items for amotivation (i.e., never thought, don't know why, and was told to; mean $[M] = 2.960$, standard deviation $[\text{SD}] = 1.330$). The Cronbach's α coefficient of the scale was .865.

Table 1. Descriptive statistics of the respondents.

Item	*Category*	*N*	*%*
Gender	Male	151	50.3
	Female	149	49.7
Age	16–25 years	4	1.3
	26–35 years	199	66.3
	36–45 years	79	26.3
	46–55 years	15	5.0
	56–65 years	3	1.0
Professional title or position	Professor/Researcher/Professor-level senior engineer	16	5.3
	Associate professor/Associate researcher/Senior engineer	75	25.0
	Assistant professor/Assistant researcher/Lecturer	104	34.7
	Postdoc	56	18.7
	Ph.D. candidate	19	6.3
	Master	20	6.7
	Other	10	3.3
Total		300	100

Table 2. Descriptive statistics of the respondents' research field.

Research field	*No. (2019)*	*% (2019)*
Physics	26	8.7
Math	12	4.0
Biology	25	8.3
Chemical	33	11.0
Earth and Astronomy	12	4.0
Agronomy	10	3.3
Engineering and Materials	49	16.3
Information Science	65	21.7
Management	23	7.7
Medical Science	18	6.0
Humanities and Social Sciences	17	5.7
Arts, Sports, and Military	0	0
Other	10	3.3
Total	300	100

Three factors were taken from *autonomous motivations* and renamed as *intrinsic motivations* (interested in participation and sense of accomplishment/realization of self-worth; $M = 5.351$, SD = 1.009), to fulfill *responsibilities* (to improve citizens' science literacy, to cultivate citizens' interest in science and promote a science culture, to popularize science culture and knowledge, to maintain scientific correctness and to change misconceptions; $M = 5.707$, SD = .854), and *personal rewards* (to augment income, to increase popularity, has positive effects on one's social network, beneficial to research, and possible career benefits; $M = 5.126$, SD = .971).

For *controlled motivation*, three factors were taken and named according to the degree of control involved: *controlled motivation I* (promote affiliation, improve the public's support, obtain support from the government, seek funding or other resources, audience demands, and the market for commercialized science communication; $M = 5.211$, SD = .893), *controlled motivation II* (work content; $M = 4.920$, SD = 1.238), and *controlled motivation III* (difficulties or failure in proceeding with the research work and finding related work, and additional tasks assigned by leaders or the organization; $M = 3.812$, SD = 1.421).

Attitudes, subjective norms, and perceived behavioral control were measured using the TBP scale [Ajzen, 1991]related research [Besley et al., 2018; Jensen, 2011; Jin et al., 2018; Martín-Sempere et al., 2008; Poliakoff & Webb, 2007], and the interview questions.

The survey had 12 items and three factors for *attitudes* (Cronbach $\alpha = .869$), including *attitudes toward participation* (important and valuable, scientists/researchers should to participate; $M = 5.810$, SD = .930), *attitudes toward the media* (the media are not rigorous, their related professional literacy needs to be improved, they tend to focus on people rather than on knowledge, they are difficult to communicate with and rarely give feedback, and there is a lack of trust and respect; $M = 3.205$, SD = 1.184), and *attitudes toward the audience* (the public's professional knowledge needs to be improved, their scientific literacy needs to be improved, they have low trust levels, they are inclined to be emotionally influenced by things, and their needs are difficult to meet; $M = 3.225$, SD = 1.128).

The survey had 16 items for perceptions of external opinions and norms about participation (Cronbach $\alpha = .889$), including four items for *subjective norms* (family/friends/colleagues, and peers/employers are supportive of my participation in science communication; $M = 5.443$, SD = .882), four items for *perceptions of policies* (relevant policies need to be improved/are inadequate and professional training in science communication is not enough/not given adequate attention by leaders; $M = 3.467$, SD = 1.302), four items for *perceptions of public opinion* (the public regards scientists involved in science communication as agents of relevant interests/are not doing their job well/not real experts/not interested in relevant scientific topics; $M = 4.007$, SD = 1.301), and four items for *perceptions of the culture within the discipline* (popularizing science is a less important activity, only scientists who cannot conduct scientific research well take part in science communication, the research field in which I am engaged does not need to be understood much by the public, and the knowledge field I am studying is difficult to popularize; $M = 4.769$, SD = 1.024).

Additionally, the survey had 13 items for perceived conditions (Cronbach $\alpha = .736$), including four items for *efficacy* (can receive good feedback, confidence in my communication ability/professional knowledge, and can change the public's attitude; $M = 5.242$, SD = .813), three items for *perceptions of time and energy* (not enough time and energy, limited personal abilities and resources, and I would like to participate when research work is progressing well; $M = 4.143$, SD = .725), three items for *related habits* (have the habit of collecting data and sharing opinions/writing articles, and I like to communicate views and values; $M = 5.200$, SD = .905), and three items for *facilitating conditions* (it is not easy to participate, reliable channels or platforms are difficult to find, and the administrative procedures are complex; $M = 3.733$, SD = 1.334).

The dependent variables were scientists' willingness to participate and their actual participation. *Willingness* consisted of one item to measure overall willingness (I am willing to participate in science communication; $M = 5.693$, SD $= 1.024$). Based on the items in related research [Besley et al., 2018; Dunwoody et al., 2009; Chen et al., 2023] and on a five-point Likert scale (1 = *very unlikely* to 5 = *very likely*), this study developed four questions on participation via different channels (overall participation, traditional media outlets, new media platforms, and other non-media forms; $M = 2.599$, SD $= .958$, Cronbach's $\alpha = .880$).

Analysis

According to maximum likelihood, the behavioral mechanism models were tested using path analysis in AMOS. To better observe and analyze the relationships between the different motivations and the variables in the models and to explore possible relationships and mechanisms, this study placed three types of motivations in the models separately and discussed them correspondingly. The variables in the models met the standard of normality assessment [Kline, 1998]. Minor modifications were made to enhance fitness, and the models remained consistent with the theories. Finally, the indices of the three models all met the acceptable range for a good model fit (Table 3). The revised model of autonomous motivation (model 1) accounted for 48.1% and 20.5% of the variance in the scientists' willingness and participation, respectively. For the models of controlled motivation (model 2) and amotivation (model 3), the respective values were 40.9% and 17.1%, and 41.1% and 20.4%.

Table 3. Fit indicators of the three models.

	CMIN/DF	*RMSEA*	*SRMR*	*GFI*	*AGFI*	*TLI*	*CFI*	*NFI*
Model 1	1.210	.026	.037	.986	.958	.991	.997	.981
Model 2	2.458	.070	.069	.958	.913	.922	.955	.928
Model 3	1.336	.035	.025	.989	.959	.984	.994	.980
Reference value	1–3	$< .080$	$< .080$	$\geq .900$	$\geq .900$	$\geq .900$	$\geq .900$	$\geq .900$

Results

The descriptive statistics, such as the mean value, standard deviation, and zero-order correlations of the variables in the models, are reported in Table 4. From the mean values, the score for scientists' willingness was above the midpoint of the scale, while that for participation was just around the midpoint, which could indicate that there might be a discrepancy between scientists' willingness and actual participation.

In the model of *autonomous motivation* (Figure 2), intrinsic motivation had a direct and significant association with attitudes toward participation, efficacy, related habits, and willingness ($\beta = .25$, $p < .001$). To fulfill responsibilities had a significant relationship with attitudes toward participation, efficacy, subjective norms, attitudes toward the media, related habits, and willingness ($\beta = .18$, $p < .01$). Personal rewards had a significant association with subjective norms, related habits, and participation ($\beta = -.15$, $p < .05$). Attitude toward participation had a significant association with willingness ($\beta = .39$, $p < .001$), and attitudes toward the media ($\beta = .19$, $p < .001$), efficacy ($\beta = .16$, $p < .05$), related habits ($\beta = .25$, $p < .001$), and willingness ($\beta = .13$, $p < .05$) had a direct association with participation.

Table 4. Descriptive statistics and correlation results.

Variable	*Correlation coefficient*															*M*	SD
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
1. Instrinsic motivation	.559***	.501***	×	×	×	×	.475***	−.115*	.327***	×	.411***	×	.390***	.537***	.129*	5.351	1.009
2. To fulfill responsibility	–	.491***	×	×	×	×	.650***	−.165**	.481***	×	.487***	×	.361***	.571***	.139*	5.707	.854
3 .Personal rewards	–	–	×	×	×	×	.342***	−.131*	.371***	×	.392***	×	.396***	.312***	.033	5.126	.971
4. Controlled motivation I	–	–	–	.352***	.229***	×	.416***	−.122*	.483***	×	.462***	−.025	.470***	.332***	.121*	5.211	.893
5. Controlled motivation II	–	–	–	–	.373***	×	.174**	−.175**	.262***	×	.173**	−.078	.243***	.155*	.077	4.920	1.238
6. Controlled motivation III	–	–	–	–	–	×	−.015	−.315***	−.021	×	−.022	−.396***	.040	.012	−.025	3.812	1.421
7. Amotivation	–	–	–	–	–	–	−.256***	×	−.242***	−.316***	−.283***	×	−.222***	−.203***	−.263***	2.960	1.330
8. Participation attitude	–	–	–	–	–	–	–	−.143*	.445***	.054	.456***	−.014	.334***	.627***	.155**	5.810	.930
9. Attitudes toward media	–	–	–	–	–	–	–	–	.036	.619***	.084	.595***	.133*	−.125*	.238***	3.205	1.184
10. Subjective norms	–	–	–	–	–	–	–	–	–	.122*	.589***	.220***	.512***	.363***	.230***	5.443	.882
11. Percieved Policy	–	–	–	–	–	–	–	–	–	–	.060	.561***	.087	−.039	.224***	3.467	1.302
12. Efficacy	–	–	–	–	–	–	–	–	–	–	–	.194**	.614***	.413***	.330***	5.243	.813
13. Facilitating condition	–	–	–	–	–	–	–	–	–	–	–	–	.237***	−.002	.289***	3.733	1.334
14. Related habits	–	–	–	–	–	–	–	–	–	–	–	–	–	.337***	.362***	5.200	.905
15. Willingness	–	–	–	–	–	–	–	–	–	–	–	–	–	–	.215***	5.693	1.024
16. Participation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.599	.958

Note: * $p < .05$, ** $p < .01$, *** $p < .001$. For the variables in the three models, "×" means that the related variables are not in the same model, although they may have correlations.

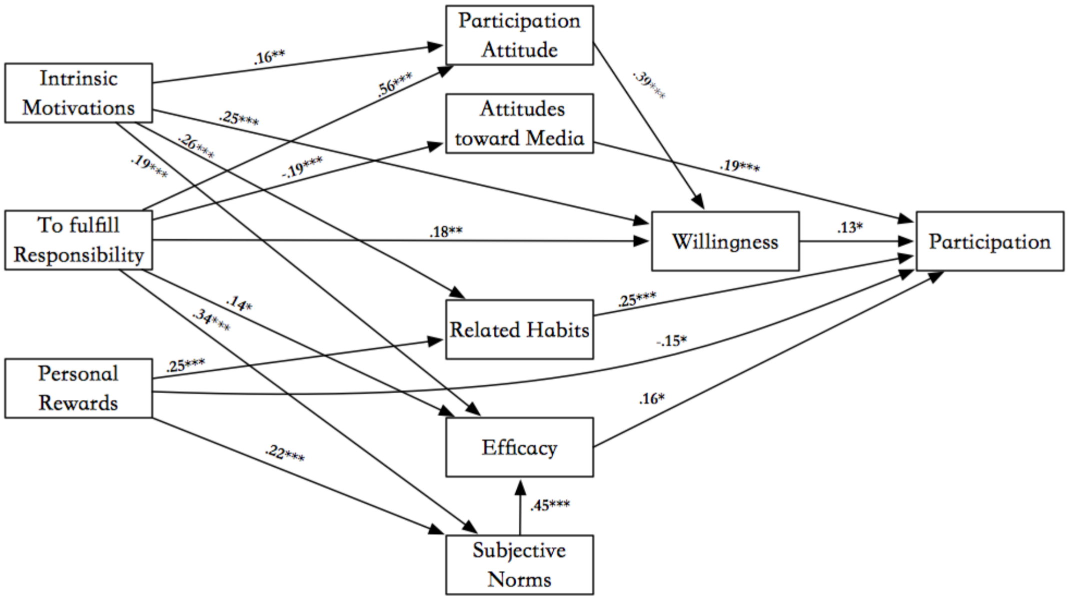

Figure 2. Research model with path analysis results of autonomous motivations (model 1, * $p < .05$, ** $p < .01$, *** $p < .001$).

Indirect effect. A bootstrapping approach was adopted to explore the mediating effects among the variables (2,000 samples drawn at a 95% confidence level). Although some variables, such as intrinsic motivation ($\beta = .13$, SE $= .03$, 95% confidence interval [CI] = [.072, .196]) and subjective norms ($\beta = .08$, SE $= .04$, 95% CI = [.015, .154]), did not have direct relationships with participation, they may contribute to participation behavior through other variables.

In the model of *controlled motivation* (model 2, Figure 3), the data show that controlled motivation I had a significant association with attitudes toward participation, subjective norms, efficacy, and related habits. Controlled motivation II had a significant relationship with facilitating conditions, and controlled motivation III had a significant negative relationship with facilitating conditions and attitudes toward the media. Attitudes toward participation ($\beta = .55$, $p < .001$) and efficacy ($\beta = .16$, $p < .01$) had a significant correlation with willingness. Related habits ($\beta = .27$, $p < .001$), facilitating conditions ($\beta = .15$, $p < .05$), and attitudes toward the media ($\beta = .14$, $p < .05$) associated with participation significantly. Willingness and participation had a direct relationship ($\beta = .15$, $p < .01$).

Additionally, some variables, such as controlled motivation I ($\beta = .18$, SE $= .04$, 95% CI = [.106, .237]), controlled motivation III ($\beta = -.07$, SE $= .02$, 95% CI = [$-.171$, $-.051$]), subjective norms ($\beta = .04$, SE $= .02$, 95% CI = [.006, .072]), attitudes toward participation ($\beta = .08$, SE $= .04$, 95% CI = [.010, .177]), and efficacy ($\beta = .027$, SE $= .015$, 95% CI = [.004, .057]), did not have direct relationships with participation, but they may contribute to participation behavior through other variables. It is worth noting that the factor with the highest level of control (controlled motivation III) had a negative relationship with the related variables.

In model 3 (Figure 4), *amotivation* had a significant negative relationship with attitudes toward participation, perceptions of policies, related habits, subjective

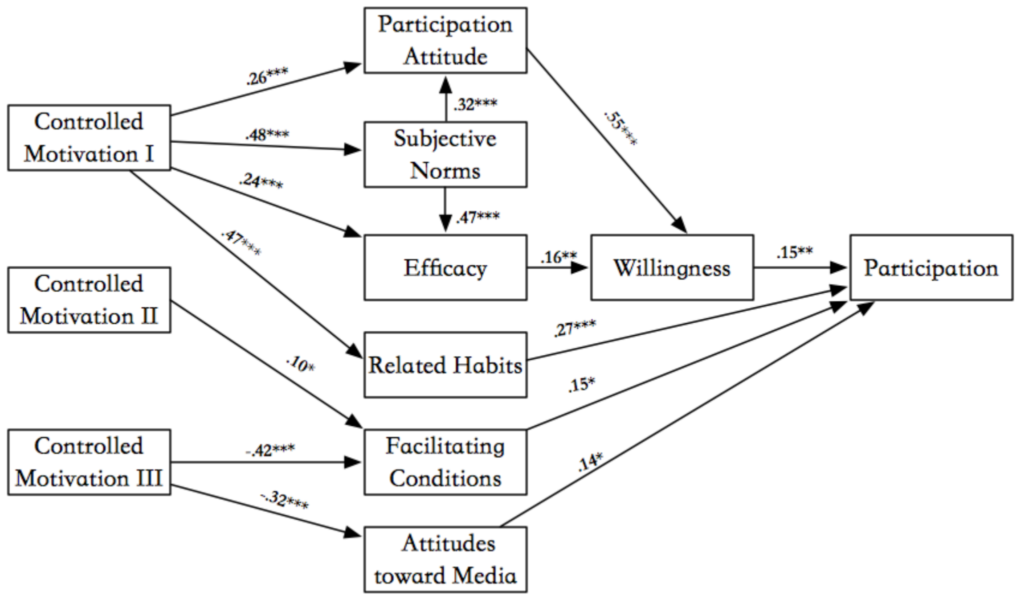

Figure 3. Research model with path analysis results of controlled motivations (model 2, * $p < .05$, ** $p < .01$, *** $p < .001$).

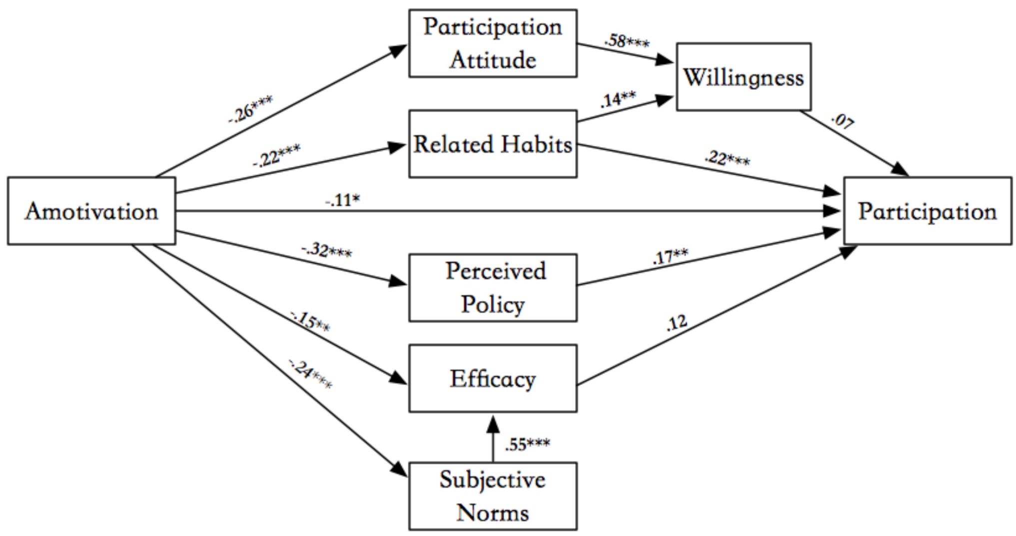

Figure 4. Research model with path analysis results of amotivation (model 3, * $p < .05$, ** $p < .01$, *** $p < .001$).

norms, efficacy, and participation ($\beta = -.11$, $p < .05$). There was a significant positive relationship between attitudes toward participation and willingness ($\beta = .58$, $p < .001$). Perceptions of policies had a positive relationship with participation ($\beta = .17$, $p < .01$). Related habits had a significant relationship with willingness ($\beta = .14$, $p < .01$) and participation ($\beta = .22$, $p < .001$). Efficacy and willingness had no direct relationship with participation. The indirect effects of amotivation on willingness ($\beta = -.139$, SE $= .035$, 95% CI = $[-.221, -.081]$) and participation ($\beta = -.108$, SE $= .027$, 95% CI = $[-.163, -.056]$) were significant. In addition, the indirect effects of amotivation on willingness (total effect $= -.139$, $p < .001$) were negative.

Discussion

This study attempted to identify the main predictors and behavioral mechanisms underpinning scientists' participation in science communication based on self-determination theory and the theory of planned behavior. On account of the level of autonomy involved according to self-determination theory, we investigated the effects of autonomous motivation, controlled motivation, and amotivation, the effects of the theory of planned behavior predictors, and their co-effects on willingness and participation. The results demonstrate that under the mechanisms of different motivations, indicators had different association with scientists' willingness to participate and their actual participation behavior. When the level of control involved increased (i.e. participants acted based on excessive pressure and compulsion from others), the negative effects also increased. Amotivation itself had a significant negative effect on participation. Therefore, even if external conditions or environments were stimulating or favorable, scientists who lacked motivation would still find it difficult to participate in science communication.

In general, various factors were involved in promoting or impeding scientists' participation in science communication, which can be described through the motivation–attitude–behavior mechanism. Motivations, attitudes toward participation and the media, subjective norms, efficacy, and habits related to communication were essential to willingness and actual participation, but they varied in their effects depending on the different levels of perceived autonomy related to the type of motivation. The mechanisms and models provide an extensive understanding of scientists' public engagement and are applicable to practices in science communication.

The motivation–attitude–behavior model of scientists' participation

Most scientists in surveys show willingness and positive attitudes toward participation in science communication, but only a small proportion of them have actually taken part in it [Jia et al., 2018; Jin et al., 2018]. This indicates a divergence between scientists' attitudes/willingness and their actual behavior. Some factors might relate to their cognitive processes and behavioral mechanisms. Self-determination theory has been used in some studies to explore the behavioral mechanisms involved, and attempts have been made to integrate this theory with the theory of planned behavior, as the combination helps explore human motivations and needs and explain behavioral phenomena comprehensively [Chan, Fung, Xing & Hagger, 2014; Hagger & Chatzisarantis, 2009].

This study attempted to explore the theoretical model of scientists' participation mechanism in science communication in China using self-determination theory and the theory of planned behavior, which is referred to as the *motivation–attitude–behavior model*. The model discusses the predictors of scientists' willingness to participate and their actual participation in science communication, evaluates the main indicators of their public engagement in different situations, and explores the behavioral mechanisms involved, allowing scientists and other individuals to participate in activities with different approaches in varied contexts. For science communities and related organizations, this model can help assess and predict which scientists are more likely and more suitable to participate in science communication, and it can also aid in formulating different incentive measures for participation in science communication.

The mechanisms of scientists' participation based on the level of autonomy of motivation

Motivations are necessary for scientists' participation in science communication, and different types of motivations have different mechanisms and association with participation. According to self-determination theory, motivations are classified according to their level of autonomy, and they have different impacts on behavior [Deci & Ryan, 2000]. In this research, three types of motivations were integrated into three models, and their different influences on participation were investigated and discussed. The results show that the three types of motivations operated under different mechanisms to influence scientists' willingness to participate and their actual participation behavior.

Autonomous motivations had important effects on scientists' willingness to participate in science communication and their actual participation, but the three autonomous motivations with different levels of autonomy had different mechanisms. In addition, the realization of these effects requires the support of other conditions or factors in certain situations. Having the highest level of autonomy in the model, intrinsic motivations had direct positive associations with attitudes toward participation, efficacy, related habits, and willingness, and it also had an indirect positive association with participation. To fulfill responsibilities had a direct relationship with some theory of planned behavior predictors and willingness, while it had a negative association with attitudes toward the media. Scientists who value their science communication responsibilities believe that the media should improve, but this would not affect their participation significantly. The consideration of personal rewards positively associates with related predictors, but it negatively associates with participation directly, and the overall effect in the model is negative. This indicates that when personal rewards are more considered or emphasized, participation is more difficult to bring about or sustain. However, personal rewards had indirect positive associations with related habits and subjective norms on participation. This is consistent with the rationale of self-determination theory — the effects of external returns on individuals should be considered in relation to the needs that the rewards satisfy, and if the rewards meet basic psychological needs (autonomy, competence, and relatedness), then the association with behavior is positive [Deci, 1971; Deci, Koestner & Ryan, 1999]. Thus, the effects of personal rewards need to be discussed on different conditions. In the final model, excluding personal rewards, efficacy, related habits, attitudes toward the media, and willingness had direct positive relationship with participation. Generally, for scientists with a high level of autonomous motivation for science communication, intrinsic motivations (e.g., cultivating interests), fulfilling responsibilities, efficacy (e.g., training), and appropriate rewards might be the incentive aspects to focus on.

As the autonomy level decreased and the control level increased, controlled motivations had different effects on the theory of planned behavior and other indicators according to the degree of control involved, whereas they had no direct relationship with willingness and participation. When the control level increased, the effects gradually became negative. This indicates that externally controlled incentives associated with scientists' willingness and participation, but excessively controlled incentives may result in negative effects. Additionally, facilitating conditions were significant only in this model and were directly related to participation. For scientists who attend science communication activities to meet requirements or for work content purposes, facilitating conditions, such as reliable platforms and uncomplicated administrative procedures, are essential. Therefore, the degree of control involved and the facilitating conditions should be considered more in decision and policy making for scientists whose participation is influenced mainly by controlled motivations.

Amotivation had a significant negative relationship with willingness, and it obviously had a negative association with participation. In this mechanism, willingness and efficacy were not associated with participation, which means that if scientists lack the motivation to participate, then their willingness and confidence to participate in science communication would not associated with their actual participation. It is noteworthy that perceptions of relevant science communication policies were directly associated with scientists' participation in this model. Thus, such policies should be considered by related management to motivate scientists to participate in this context.

In general, autonomous motivations that could promote scientists' voluntary engagement in science communication had a positive relationship with scientists' willingness and participation. The effects of controlled motivations that stimulate voluntary or compulsory participation depended on the degree of control involved. For those scientists who lack motivation to engage, having relevant science communication policies would be appropriate.

The necessity for incentives

How to increase the number of incentives for scientists to participate in science communication and motivate them has long been a concern in this research field. Most respondents completing this survey believed that more incentives should be created or that current incentives should be improved. Based on the current situation and the results of this study, improved incentives are indeed necessary. First, motivation was found to be one of the fundamental factors associated with behavior, and scientists' participation motivations were partially generated or driven by external stimuli. Although endogenous motivations may be stronger and may last longer in some circumstances, without external incentives, behavior is difficult to bring about or sustain. Second, in the third model of amotivation, it was found that policy plays an important role in the motivation–attitude–behavior mechanism. For scientists who lack the motivation to participate, policy incentives may thus be among the most effective ways to encourage them. Third, incentives may include not only policies but also cultural aspects, which fall under social norms. In the three models, subjective norms were not directly associated with participation intention or behavior, but they affected the models nonetheless. Finally, the role of willingness in prompting participation was significant and direct in the autonomous and controlled motivation models, and willingness was associated with motivation and other predictors. Participation willingness can also be cultivated and activated in certain ways. For example, according to the survey data in this study, more than 50% of the scientists believed that participating in relevant training could increase their participation and willingness. Therefore, incentives are necessary and should be created systematically and appropriately according to different contexts.

Limitations and future research

This study has several limitations. First, in the development of the theoretical model, this study attempted to integrate the theory of planned behavior and self-determination theory. However, the models and studies based on these two theories have been discussed and tested mainly in other research fields, so a stronger application of the model to this topic may require greater empirical support. Second, we only maintained the significant predictors in the motivation–attitude–behavior mechanism and models, but other factors could also associate with willingness or participation, such as experience and feedback [Besley et al., 2018; Dudo, 2013; Torres-Albero, Fernández-Esquinas, Rey-Rocha & Martín-Sempere, 2011], personality [Tsfati et al., 2011], and demographic factors [Bentley & Kyvik, 2011]. Third, longitudinal and experimental studies are more appropriate for understanding causality to predict participation and to better explore its mechanisms. Fourth, this combined model and related questionnaire can be applied to future research studies in other countries, and also facilitate national comparative studies.

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