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Towards Understanding the Causal Relationships in Proliferating SD Education—A System Dynamics Group Modelling Approach in China

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Abstract: Given the growing importance of system dynamics (SD) in solving increasingly complex and dynamic problems in any country, we believe SD education will become an imperative leverage point in helping us deal with our uncertain future. This study tries to understand the causal relationships in proliferating SD education by a system dynamics group modelling approach in China. Based on a questionnaire survey and a group model building (GMB) workshop, we aim to explore the interactions of feedback loops in the constructed causal loop diagram (CLD). This uncovers insights into what constitutes the growth of SD education in China and helps to guide the design and implementation of policies to achieve this growth. We conclude that it is important and relevant to find ways to improve, including the construction of an SD teaching platform to integrate normative resources, providing opportunities for teacher training, enhancing the availability and accessibility of SD education, and building networks with international partners. The results of our study may set the foundation for further research to extend the generalizability of our insights and methodological approaches to other countries.

Keywords: causal loop diagram; group model building; system dynamics education; questionnaire survey

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1. Introduction

System dynamics (SD) is a method for studying and understanding the behavior of complex systems over time. It focuses on practical applications and case studies, using computer software to model and analyze complex systems. SD was first developed by Jay Forrester in the mid-1950s [1,2] and has been introduced to the Chinese mainland for more than 40 years. Initiated by advocates such as Tongyi Yang, Qifan Wang, Qingrui Xu, Yukui Hu, Zaipu Tao, and so on, SD has experienced considerable development since the 1980s in China [3].

China is the second-largest economy and the biggest emitter of carbon dioxide emissions in the world. It is undergoing difficult challenges for the foreseeable future, such as population aging [4], carbon neutrality [5], and social equity [6]. These challenges are complex, dynamic, and highly interactive with each other. SD is indispensable in seeking sustainable solutions and improving our chances to effectively address these issues. Meanwhile, the world has become more hyper-connected than before [7]. The change in China

has a greater impact on the world. Therefore, enhancing the development of SD in China is essential not only for itself, but also for the world. However, there are increasingly complex problems that are difficult to address, for example, ecological poverty alleviation, city planning [8], food security [9], sustainability [10], public health [11], and so on. Using SD, decision-makers in China can better understand how factors interact and impact the whole system and solve problems more effectively. Hence, it is an important opportunity for SD as a field to contribute to policy formulation in China now.

Over the years, the teaching of SD in China has evolved. Many universities and institutes in China now offer courses and degree programs in SD. These programs typically include theoretical and practical components and often use case studies and real-world examples to illustrate the concepts being taught. While the challenges in developing the field to meet the demands of the real world have been difficult, e.g., lacking sufficient know-how in the effective teaching of SD and low awareness of the industry about the usefulness of the method, among others. Taking the degree of SD development in China as a stock, we can see that the inflows are capabilities of educators and practitioners, public awareness, and application in fields, while the outflow is people giving up and switching to other fields. With the development of SD in China, the capabilities of SD educators and practitioners will help to tackle the challenges and meet society's needs. This is why we investigate the status quo of SD education in the Chinese mainland, concentrating on the causal relationships in proliferating SD education and providing policy recommendations to improve, which can be lessons to the rest of the world.

Compared with its wide application in different fields, there is a lack of study on SD education, particularly in China. Davidsen et al. described the systems of education at the University of Bergen and its impact on ST and modeling throughout the world [12]. Pavlov et al. presented the design and rationale for undergraduate and graduate programs at Worcester Polytechnic Institute [13]. Fisher introduced a successful SD modeling approach used for almost a quarter-century in secondary schools in the USA [14]. Schaffernicht et al. put forward a competence development framework for learning and teaching system dynamics based on a three-round Delphi study [15]. However, the education of SD in China is little-known. Professor Wang Qifan commented on the development of SD in China and analyzed its tasks in 1987 [16]. Yan et al. focused on the course design and exploration of SD simulation [17]. Therefore, our work can contribute to the existing studies in two aspects. Firstly, to the best of our knowledge, there is very little research carried out in our area. To ensure the rigor of our research, we leverage a similar Delphi method in accordance with our research objectives and design. Secondly, this work innovatively adopts a system dynamics group modelling approach to investigate the causal relationships in proliferating SD education. We take special care to document our process and the rationale behind each process step so that others can replicate our approaches to evaluate SD education in their context. Therefore, it offers a roadmap for others to emulate, and thus contributes to the development of SD education across the globe.

2. Methodology

Drawing inspirations from extant literature on methodological approaches that rely on experts [18], our methods consist of the following process (Figure 1).

The Systems Engineering Society of China (SESC) is a national-level society established in Beijing in 1980, with 29 technical committees. It is the highest national level society that plays an important role in shaping the development of China through advisory to leaders and driving impactful research. Only the highest qualified experts recognized by the China government and the research and practitioner's community can become members of the society and its technical committees. The SD technical committee in SESC is composed of leading experts recognized by both government and practitioners. It is, therefore, an appropriate theoretical sample for us to elicit its experts to investigate the current state of SD education in China.

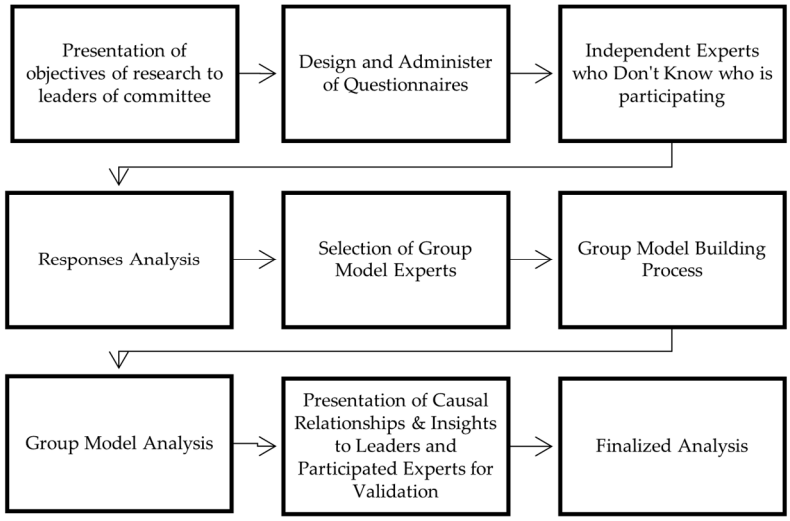

Figure 1. Research process chart.

The works of the SD technical committee are coordinated through a WeChat group, to which we have access. We reached out to more than 270 experts (who are highly recognized researchers, educators, and/or practitioners for their knowledge, capabilities, and independence) to elicit their support to share their expert views by completing a survey questionnaire that we had designed. These experts' selection criteria are aligned with the extant literature that depends on experts to offer unique insights into their research questions [19]. A copy of the survey questions asked is provided in Appendix A.

The questions in the survey were developed by consulting similar literature that attempts to evaluate the current state of education in a particular field [19], and we contextualized them to China and SD. We consulted this literature in the design of our questions because very little research has been carried out in our area and we want to ensure the rigor of our questions by leveraging on similar research in accordance with our research objectives and design.

The response from our experts provided an important starting point to help us narrow down the specific causal relationships that deserve closer examination through a GMB process. The adaption of a GMB process is useful for our context because it engages our experts in developing an increased understanding of our problem and increased the agreement on the joint actions going forward for SD education in China, as advocated by Vennix et al. [20], and it is particularly suitable for 'messy' problems such as SD education in a large country like China [21].

Causal loop diagrams (CLDs) are a qualitative diagramming language for representing feedback-driven systems. It is an important phase of systems thinking and system dynamics methodologies [22]. Systems thinking has been widely applied in many fields, including business, engineering, social science, economics, and so on. It is a valuable tool for management [23]; for example, problem-defining, decision-making, and problem-solving. Meanwhile, the use of ST in education also has a long history, mainly as a teaching method to help students master knowledge more efficiently in the classroom [24]. However, systems thinking and CLDs have likely become increasingly used by educators as they have demonstrated superiority in better understanding the complex educational system. Systems thinking can be used to design new programs or interventions. Monat et al. explained the importance of teaching systems thinking to undergraduate engineers and proposed an approach to inculcating ST into engineering curricula [25] Wheat combined ST with macroeconomics [26] and Shi explored and practiced new teaching methods with ST [27]. Furthermore, Minarik used ST to address teacher retention challenges [28] ST can help teachers to understand the whole teaching system and manage or improve their teaching feedback, including but not limited to curriculum design, student learning, teaching

practices, funding application, and innovation. ST, with an emphasis on eliciting information from real-world participants, should contribute useful insights to SD, so it is an appropriate qualitative analysis methodology for this study.

Using the data collected from the survey, we designed a GMB workshop's scripts drawing inspiration from well-established group model building literature [21,29] to assure the rigor of our design. GMB is a participatory approach to the development of system dynamics models for creating a shared understanding of complex systems and providing a platform for stakeholders to exchange information and ideas [30].

The objective of the workshop is to work with the identified experts to uncover the causal relationships that led to the results presented in the survey. To assure the success of our model building process, we implemented the following measures:

(1) We pilot tested our model building process prior to the actual implementation and fine-tuned it based on the feedback provided by the pilot group. The pilot group members are selected key leaders of the technical committee similar in demographics to our targeted experts.

(2) We incorporated key principles into our design process in addition to those best practices advocated by the extant literature to maximize the depth of discussion during the model building process. Two of the most important principles are summarized below:

a. "Every view should be shared and heard"

We design process steps to avoid group thinking or a dominant view overwhelming the conversation. For example, we ask every member to think about our posted question individually first (e.g., draw the behavior over time graphs of variables that affect SD education in China directly) before we allow people to share. After this, we ask members to vote for which variables are most important among those that are being shared, ensuring that the principle is upheld.

b. "Respect each other differences and keep the space safe"

We have professional facilitators to ensure that people do not go into the vicious cycle of judging and criticizing each other viewpoints during the model building process and set up group rules in the beginning to remind participants of the importance of adhering to this principle.

Because of the inconvenience of organizing an in-person session due to the pandemic prevention and control, we decided to carry out the workshop online on 12 November 2022. The digital platform we chose was Tencent Conference because it is stable and widely used in China and all the participants are familiar with it. Six participants with two facilitators in this study were scholars working in the fields of SD teaching, practice, or research from different universities and institutions in China. Purposive sampling was used in the first instance to recruit scholars with a solid SD background who had been involved in GMB practice or SD educators. Our sampling strategy enabled the recruitment of participants from different age groups, school types, and geographical areas, allowing the exploration of a range of perspectives and experiences.

The main steps of the GMB workshop were essentially similar to the original scripts with minor changes. The scripts we used are as follows (detailed scripts are provided in Appendix B):

a. Introduction;
b. Hopes and Fears;
b. Graphs over Time;
c. Variable Elicitation;
d. Initiating and Elaborating a Causal Loop Diagram;
e. Leverage Point and Action Plan;
f. Model Review and Feedback.

The GMB session lasted for 4 h, excluding the "Model Review and Feedback" step, which was completed one day after the session. All of the participants reviewed the constructed CLD and provided further advice.

3. Results

In this section, we first describe the statistical summary of the survey, which shows the status quo of SD education in China. We observed from the open questions that teaching and researching are often mutually influenced. Thus, the CLD based on the GMB practice contributes to a deeper analysis to explore the interactions influencing the development of SD in China.

3.1. Questionnaire Survey Results

Of the 271 members in the WeChat group, 38 experts responded to our call between 12 and 20 August 2022, forming a response rate of around 14%. This is much higher in terms of both absolute numbers and the response rate achieved by extant literature that depends on experts for their research [18,29,31]. A closer examination of the participants' demographics also revealed that the participants are from 32 organizations spread across 15 provinces in China (Figure 2). This gave us confidence that the results captured insights and need on SD education across diverse geographical locations and the organization's context in China.

To further enhance the reliability and validity of our collected survey data, we presented the aggregated data to key leaders and experts within the SD technical committee in China and the Policy Council of the System Dynamics Society (an international society with thousands of members globally, started by the founder of the SD field, Professor Jay Forester). We received concurrence from senior leaders from both the technical committee and the international policy council on the representativeness of our experts' selection and the relevancy, importance, and the extensibility of our research to other countries in driving SD education globally.

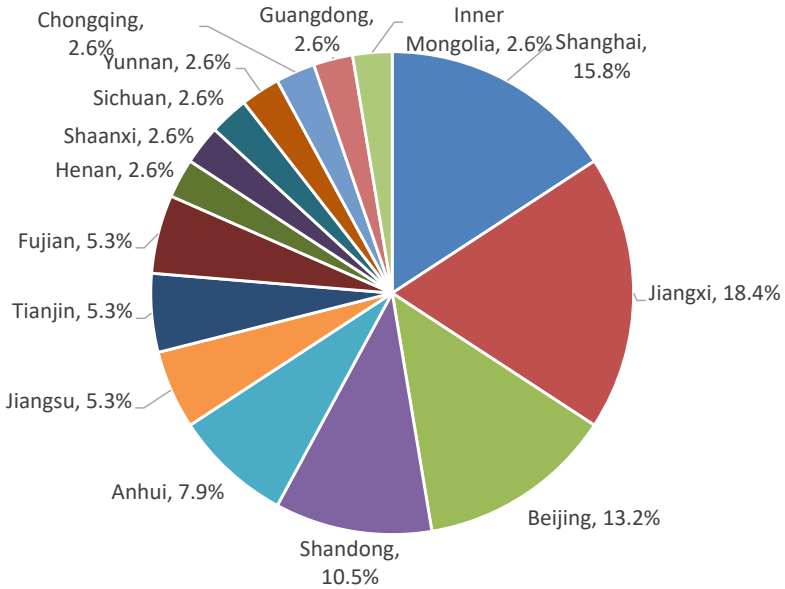

Figure 2. Distribution of SD scholars by provinces.

As Table 1 shows, a total of 55 SD courses are offered at different levels. In total, 2220 students from high school to Ph.D. degrees participated in SD-related courses in 2022. Of the students, 57% are undergraduates and 41% are masters and Ph.D. students. The distribution of students and courses is shown in the figure below (Figure 3). "Junior" and "Master" (Master's Degree) are the highest concentrations.

Table 1. Summary of SD teachers and courses.

Province	Institutes	No. of Teachers	No. of Curriculums
Shanghai	University of Shanghai for Science and Technology	2	3
	Shanghai Academy of Social Sciences	1	1
	Shanghai University of International Business and Economics	1	1
	Fudan University	1	1
	East China Normal University	1	1
	East China Jiaotong University	1	1
Jiangxi	Nanchang University	3	4
	Jiangxi University of Finance and Economics	1	2
	Jiangxi Science and Technology Normal University	1	3
	Nanchang Hangkong University	1	2
Beijing	Beijing University of Civil Engineering and Architecture	2	3
	Central University of Finance and Economics	1	2
	Beijing Jiaotong University	1	2
	Beijing University of Technology	1	1
Shandong	Shandong University	2	2
	Shandong Technology and Business University	1	2
	Qingdao University	1	2
Anhui	University of Science and Technology of China	1	2
	Huaibei Normal University	1	1
Jiangsu	China University of Mining and Technology	1	2
	High School Affiliated To Nanjing Normal University	1	1
Tianjin	Tianjin University of Science and Technology	1	2
	Tiangong University	1	1
Fujian	Huaqiao University	1	1
	Xiamen University of Technology	1	2
Henan	Henan Agricultural University	1	2
Shaanxi	Xi'an University of Science and Technology	1	2
Sichuan	South Western University of Finance and Economics	1	2
Yunnan	Yunnan University	1	1
Chongqing	Chongqing College of Mobile Communication	1	1
Guangdong	Sun Yat-sen University	1	1
Inner Mongolia	Inner Mongolia Agricultural University	1	1

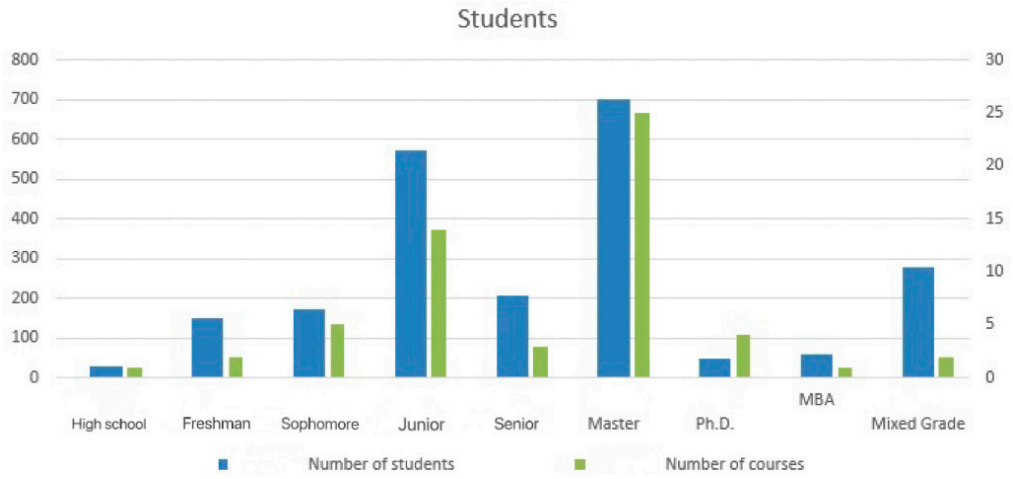

Figure 3. Grade distribution of students.

Among the 55 courses related to SD, 41% are compulsory courses and most courses (80%) are offered once a year. The course covers many fields, including SD, systems engineering, public management, modeling, and simulation. Note that only about 20% of the courses listed by the survey are SD. The next highest are systems engineering and management (about 10%).

In terms of the teaching feedback, both teachers and students were satisfied with the SD courses. Of the respondents, 76.5% believed that teaching SD-related courses promoted academic research. Most teachers agree that SD courses can improve students' critical thinking ability (94.1%) and modeling ability (70.6%), and they can help students in scientific research work, such as paper publication (50.0%) and competitions (11.8%). In the teaching process, teachers face some difficulties, especially in the building of the teaching team (55.9%) and the course platform (41.2%). Some teachers have not found suitable teaching material (29.4%) or cannot get strong support from their institutions (14.7%).

3.2. CLD Construction through a GMB Session

Based on the survey results, we discovered that it is worth exploring the driving forces and obstacles in SD education in China. To construct the CLD, we first need to define a developmental problem, which is an internal behavioral tendency found in a system [32]. Such a problem description is called a reference mode in system dynamics modeling. The participants in the GMB session voted and reached a consensus that the reference mode in this system is the influence of the development of SD (influence of SD in short).

For the social science discipline, the academic development force includes two aspects: academic productivity and academic influence [33]. Academic productivity mainly refers to knowledge innovation ability, which is mostly evaluated by academic papers, monographs, consulting reports, and so on. In our case, we use high-quality SD research and consulting projects as one indicator to evaluate the academic productivity aspect. Academic influence refers to the response of research results in academia and society [34]. We choose the number of students taking SD-related courses to evaluate the academic influence of SD. With more students taking SD-related courses, social benefit will be achieved accordingly, which is associated with self-development and work efficiency brought by applying SD. Maani and Maharaj found that individuals who display the characteristics of systems thinkers, even if they are unaware of the fact, perform better on complex decision-making tasks [35]. This is typical proof of SD's social benefit and academic influence.

Each participant shared their hopes and fears for the field and drew the graphs of the development trend over time (Figure 4) based on their experiences and understandings.

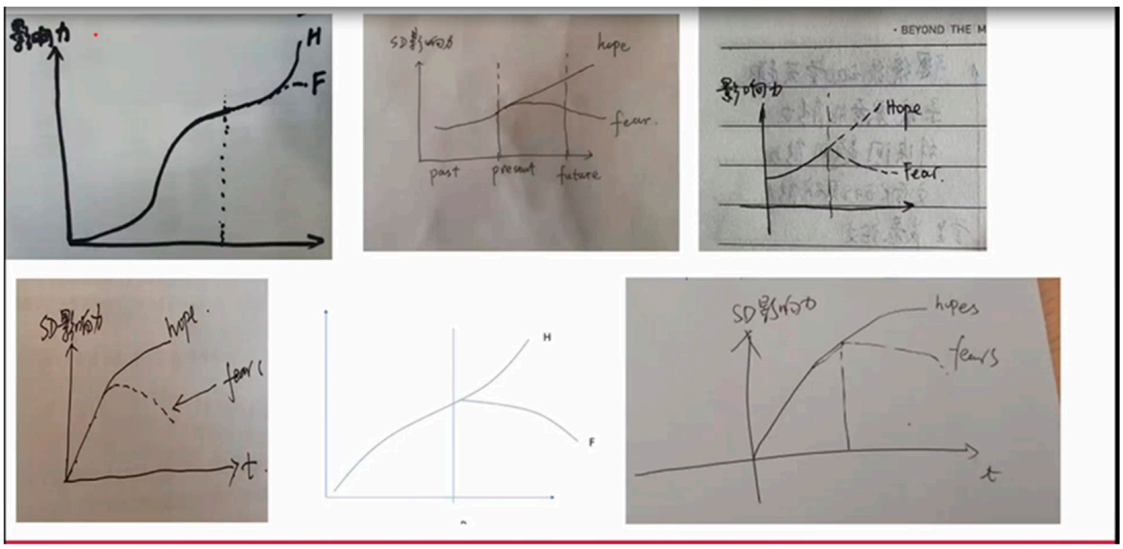

Figure 4. Reference mode graphs drawn by GMB participants. The horizontal axis "t" represents time, with a longitudinal dividing line separating the past and future with the present. The vertical axis "SD 影响力" represents the "influence of SD" in the graphs.

In the following part, we explain the constructed CLD (Figure 5) from the major reinforcing and balancing feedback loops.

The three reinforcing loops (R1–R3) and one balancing loop B1 show the dynamic process of the influence of SD through teaching efforts. With the gaining influence of SD, students' interest is promoted, more schools are willing to offer SD courses, and the number of courses offered relating to SD will increase the number of students taking SD courses, all of which enhance the influence of SD. With the enhanced influence of SD, more people are willing to teach and perform research in the field of SD, and high-quality SD research and consulting projects produced by professionals will obviously improve the influence of SD (R4) from the research aspect. Of course, with a comparatively long delay, the increasing number of students taking SD courses will eventually raise the number of professionals in the field and grow the influence of SD through high-quality research and consulting projects (R5). Teaching capacity and teaching quality will improve with the increasing number of professionals, thus leading to the students learning effectiveness and attracting more students to take SD courses (R6). The balancing loop B1 shows that lower teaching quality brought by students' scales may directly influence students' learning effectiveness, and they may lose interest in taking SD courses.

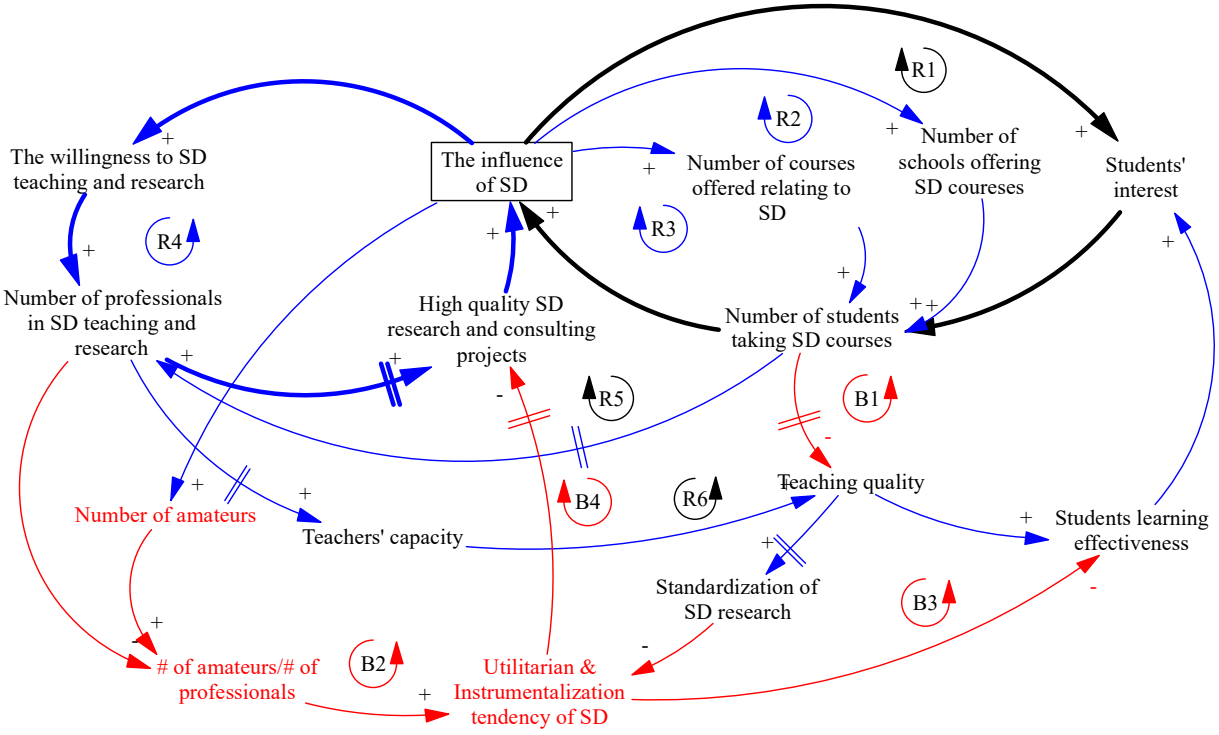

Figure 5. Causal loop diagram of the development of SD education in China.

It is worth mentioning that the most important fear discussed in the GMB session is the influence decreasing as a result of the utilitarian and instrumentalization tendency of SD. Here, the utilitarian and instrumentalization tendency of SD refers to the fact that people tend to take advantage of SD methodology as just a quick fix to their research without fully mastering the theory, so there exists misunderstanding and even misuse of the SD methodology. We identify the causes as follows.

On the one hand, improving the influence of SD may attract more people who have not been well-educated in SD-related fields to use SD as amateurs. With the increasing proportion of amateurs to professionals in the field, the rising of the utilitarian and instrumentalization tendency of SD is inevitable (B2). On the other hand, the increasing number of students taking SD courses may lower the teaching quality. Without high teaching quality, the standardization of SD research cannot be guaranteed (although it will not happen any time soon), which leads to the utilitarian and instrumentalization tendency of SD. This tendency has two consequences. One is that it directly affects students' learning effective-

ness (B3). The other is the emergence of low-quality SD research and consulting projects by abusing and even misusing the SD method, which reduces the influence of SD (B4). It is to be noted that some of the overlapped loops are not labeled in the CLD for a clear understanding of the major loops.

4. Discussion

From the construction of the CLD, we can explore the driving forces (reinforcing loops) increasing the influence of SD in China through teaching, doing research, and their mutual interactions. While at the same time, there may exist constraints that limit the growth of the influence of SD, as the four balancing loops illustrate. This means the reference mode of the influence of SD somehow shows an S-shaped growth, as shown in Figure 4.

The actual development of SD in China presents the same trend. SD has experienced growth since the subject was introduced to China in the 1980s. The SD community in China was active and attracted a large number of scholars to devote themselves to this field. Plenty of papers and major scientific projects using SD as the methodology emerging accordingly. As shown in Figure 6, using system dynamics as the keyword when searching publications in the China National Knowledge Infrastructure (the world's most comprehensive online resource for accessing China's intellectual output), the publications experienced sluggish growth thereafter and were even on the trend of a slight decline for some time. Most participants are concerned about the declining trend if the balancing loops dominate.

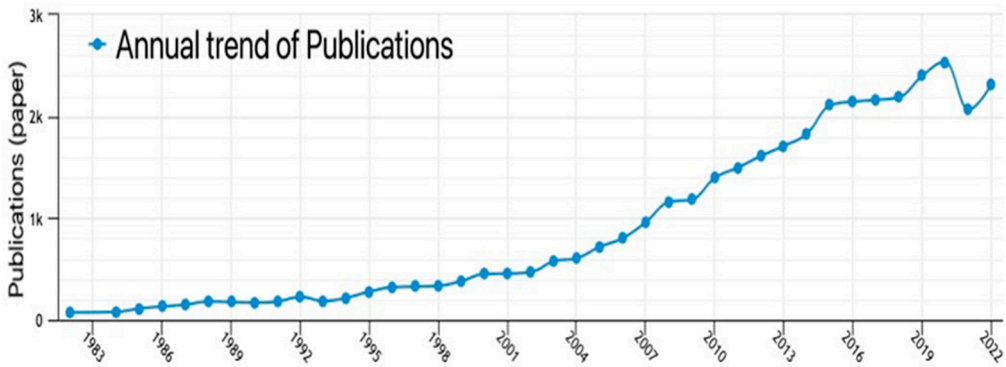

Figure 6. Publications by year in the China National Knowledge Infrastructure.

Developmental problems are often perceived as existing conditions, which must be alleviated. The CLD analysis also provides added insights into the possible leverage points to promote development and avoid the declining trend. In Figure 4, as we can see, there are also delays in the balancing feedback loops B1, B3, and B4, especially between the number of students taking SD courses and teaching quality, utilitarian and instrumentalization tendency of SD, and high-quality SD research and consulting projects. The significant delay that exists in loop B3 shows that teacher's capacity may not improve in accordance with the increasing number of students, which will tend to decrease teaching quality. Thus, there might be oscillations in the number of students. When the utilization and instrumentalization tendency of SD rises, high-quality SD research and consulting projects will tend to decrease, but only after significant delays while new publications are made available and new projects are applied. Thus, eliminating the utilitarian and instrumentalization tendency of SD and improving teaching quality serve as the main leverage points in this regard.

In the GMB workshop, combined with the valuable survey results, we proposed two policy recommendations: the construction of the SD platform and opportunities for teacher training (Figure 7).

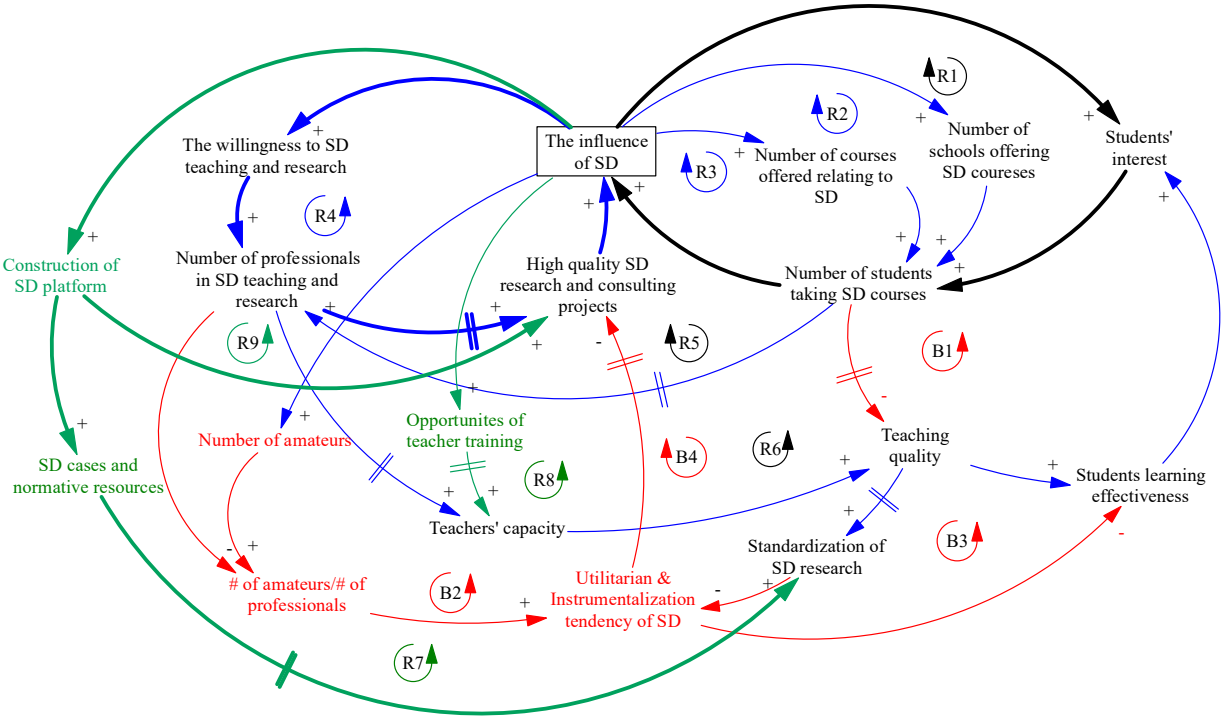

Figure 7. Causal loop diagram with policy recommendations.

- Construction of SD teaching platform

The construction of the SD teaching platform contains valuable cases, models, and other normative research and teaching materials, which can effectively prevent wrongly informed students and improve the quality of research. The feedback loop R7 shows this policy suggestion of improving the standardization of SD research to avoid the utilitarian and instrumentalization tendency of SD through the construction of an SD platform, which can weaken the negative effects brought by loops B2–B4. The construction of the SD platform also provides opportunities for academics, government, and industries to apply SD and contribute to the improvement of high-quality research and consulting projects (R9).

Why is it necessary to construct an SD teaching platform? Since SD was introduced to China in the 1980s, relevant textbooks have been published and updated one after another, including the earliest textbook System Dynamics written by Professor Wang Qifan [16], Advanced System Dynamics written by Professor Jia Renan [36], and the most recent one written by Professor Zhong Yongguang [37], among others, which have provided a good foundation for SD teaching and research. However, with the development of the subject and the diversified needs of the audience student groups, the drawbacks of the existing textbooks have gradually come to the fore. For example, the survey shows that less than half (15) of the 38 teachers who offer SD-related courses use domestic textbooks and five of them use foreign textbooks.

The survey results show that a possible way to improve SD teaching is the construction of cases and teaching materials; for example, "there is no uniformity in the standardized typical cases and hot cases, and I hope that there will be related teaching materials and a related teaching virtual platform" (from questionnaire response 5); "it would be better if there are more interesting courses and teaching materials (from questionnaire response 23)"; and "It is only valuable to combine practical case applications, practical case development to stimulate learning interest and improve Practical application cases" (from questionnaire response 16), among others. This means that there is still a shortage of cases and teaching materials that can be used directly in classroom teaching practice, and there are even fewer classroom cases that reflect the normative, classic, and usable nature of the SD approach.

Many classical case models, such as the epidemic model and the bullwhip effect model, as well as real-life problems that combine with the reality of Chinese society, such as the aging population and the macro-level national economy, are all typically quite knowledgeable and representative. Therefore, the platform can also include relevant case models, which can be edited and published as a collection of SD case models to supplement the teaching materials for classroom use. The case model sets standardize the ideas and methodological steps of SD modeling with vivid examples and are accompanied by guidelines for classroom use and corresponding models. The interactive platform can also be used to provide a modifiable model to facilitate operations such as model extensions according to different conditions during the lecture, which can fully motivate students and stimulate their interest in learning. At the same time, the standardized modeling process learning also lays the foundation for improving students' independent modeling skills and uniform academic specifications.

Domestic scholars have also carried out a lot of innovative work in platform construction and the creation of teaching materials. For example, Professor Jia Xiaojing of the Central University of Finance and Economics led the first domestic MOOC course named "Systems Thinking and System Decision Making: System Dynamics" (https://www.icourse163.org/course/-1003481004, accessed on 26 November, 2022), which broke through the physical boundaries of lectures and made a breakthrough contribution in expanding the radiation and influence of SD teaching.

- Opportunities for teacher training

Teacher training at all levels is much needed by teachers who are involved in SD teaching and research. With the enhancement of the influence of SD, more opportunities for teacher training are proposed to promote teachers' capacity, which is key to the improvement of teaching quality. The improvement of teaching quality is an accumulating process with significant time delays, but it is worth trying to realize the standardization of SD research, which aims to eliminate the utilitarian and instrumentalization tendency of SD and enhance students' learning effectiveness (R8).

Training on course design and teaching methods. Owing to the characteristics of SD, it is difficult for students to master it deeply in a short time, especially teaching quantitative models effectively to students without a strong science background, which is a problem commonly encountered in teaching practice. It is possible to start by replicating classical models and then expand on them and move on to model building for their own projects once they have mastered certain modeling techniques. Students are encouraged and guided to build on the literature, which also requires SD lecturers to keep track of recent developments in the field. The literature is appropriately selected for the direction of student research in theoretical teaching, with explanations of model building, testing, and simulation. It also provides opportunities for student rehearsals, more interaction between teachers and students and between student groups, and more hands-on and interactive time for students in the classroom to reinforce independent modeling training as well as mindset stimulation training.

In addition, in the design of the curriculum, it is more important to arrange the levels of instruction for different students. For example, a focus on system-thinking-related content in the forward course, and subsequent bridging courses focusing on SD modeling and other aspects of training, which is more helpful to students' understanding and mastery.

Joint cross-campus lesson planning is a higher-order form of curriculum design and, by building a hybrid teaching curriculum, the SD teaching curriculum design and delivery methods can be improved [12]. It can also increase the impact and reach of SD to a certain extent. It can also be carried out in parallel with the aforementioned case development and textbook development, creating a synergy to improve and optimize SD teaching.

Training on interdisciplinary teaching and research. The survey shows that more than 40% of the faculties currently offering SD-related courses in China are in business or management schools, and 73.7% of the highest degrees obtained by the faculty involved in teaching are in management science and engineering or management. Of the 55 SD-

related courses, 25 were directly titled SD or ST. The remaining courses covered a variety of areas, including regional economic planning, industrial engineering, land reclamation engineering, socially complex systems, public management, tourism systems analysis, national studies, and modern management. In particular, in the courses where SD is not taught in its entirety, teachers integrate the core ideas and theories of SD with other disciplines, working to improve students' ability to think systematically, gain a deeper understanding of complex systems, and think about solutions to complex problems and model them.

On how to conduct interdisciplinary research, Allen Repko suggests that interdisciplinary research is the process of answering questions, solving problems, and addressing issues that are too broad and complex to be solved by a single discipline; it is discipline-based and aims to integrate insights and build a more comprehensive understanding [38]. Therefore, interdisciplinary education advocates a "problem-oriented" pathway to knowledge, which has a new understanding of knowledge [39]. As a comprehensive discipline at the intersection of understanding and solving system problems, the natural interdisciplinary properties of system dynamics place it more in line with the requirements of pluralistic integration.

There are some online teaching and training events organized by international societies, but, because of the time difference and other issues, such opportunities are not available for Chinese scholars.

Training on fostering scholarly communications. International cooperation and exchange through international conferences and other forms are mostly at the research level; for example, the survey results show that most teachers hope that the SD Society can provide opportunities for international collaborative research (67.7%) and finance support for academic conferences (64.7%). In addition, the coordination of the SD Society to provide opportunities for high-level research would encourage more foreign professors to accept Chinese faculty and students to study and visit abroad.

The internationalization work of the SD Committee has always been recognized by the Systems Engineering Society of China. We have been continuously exploring organizing international conferences and international talent cultivation. However, it is still a shortcoming in international collaborative teaching. In terms of international collaborative programs, it is hoped that foreign professors can be invited to their courses as visiting professors and participate in mentoring students in modeling projects, among other flexible forms.

The development of collaborative degree programs is also a key focus of international cooperation. Since 1997, Professor Wang Qifan and the University of Bergen in Norway have initiated a professional master's training program in SD. By 2011, 30 students had participated in the program, most of whom have gone on to further studies and further careers in SD research and teaching after graduation. The joint SD Ph.D. program between Shanghai University of International Business and Economics and the University of Palermo has been running since 2014 and, so far, five Ph.D. candidates have been enrolled, two of whom have successfully graduated and are working in SD-related jobs in universities and research institutes. The development of these projects is a good example of how international cooperation facilitates scholarly communications over time to achieve a sustainable promotion of SD education.

5. Conclusions

Given the growing importance of SD in solving increasingly complex and dynamic problems in any country, we believe SD education will become an imperative leverage point in helping us deal with our uncertain future. The questionnaire survey results reveal very interesting facts and are worth further exploring. Thus, a GMB workshop is applied to explore the causal relationships in proliferating SD education. We explore the feedback mechanisms influencing the development of SD in China with a CLD analysis. This is the first time that a panoramic view of SD teaching and learning is available across the

Chinese mainland. Although, there are problems with this study in terms of its lack of breadth of scope, the slight singularity of the research channels, and the depth of analysis that needs to be improved. The status quo of SD teaching reflected in the study shows the overall situation at the teacher level and student level, as well as various difficulties in the teaching process specifically in terms of teaching design, pedagogy, and teaching materials, among others.

Possible policy recommendations for improvement were also collated based on the survey results and CLD analysis.

(1) To construct an SD teaching platform to improve the standardization of SD research and avoid the utilitarian and instrumentalization tendency.
(2) To create more opportunities for teacher training to promote teachers' capacity.
(3) To incorporate SD with other disciplines and encourage interdisciplinary research.
(4) To strengthen international collaboration in both SD education and research.

The results uncovered in our research offered important causal relationships and variables that need to be considered when attempting to drive the proliferation and effectiveness of SD education. While it may not be entirely relevant to the development of SD education in another country, our research had set the foundation for further research to extend the generalizability of our insights and methodological approaches to other countries.

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Appendix A. Questionnaire

This survey aims to understand the education of system dynamics (SD) in China, to provide decision-making support for the International Society for system dynamics China Chapter to serve better and support the development and promotion of SD education in China. The survey is anonymous, and the results will only be used for research purposes and will not negatively influence you. Please do not hesitate to fill in the relevant information truthfully. Thank you for your support and cooperation!

SD China Chapter
5 August 2022
Part I. Personal information:

1. Your name: _____
2. Your affiliation (specific to the college):_____
3. Your age:

☐ 20–30
☐ 30–40
☐ 40–50
☐ 50–60
☐ 60 and above

4. Your highest degree:

☐ Undergraduate
☐ Master's degree
☐ Doctoral degree or above

5. The subject of your highest degree:
6. Where did you obtain your highest degree

☐ Current university
☐ Other domestic universities
☐ Foreign universities

7. Your academic title:

☐ Lecturer
☐ Associate Professor
☐ Professor

Part II. SD teaching situation:

8. The name of the SD-related course you teach: _____
9. The earliest time that your university offered the SD course: _____
10. The frequency of the SD course you teach:

☐ every semester
☐ every year
☐ other

11. The students you teach (multiple choices):

☐ Undergraduate lower grade
☐ Undergraduate higher grade
☐ Master's degree
☐ Doctoral degree

12. The size of the class:

☐ 20–30 people
☐ 30–40 people
☐ 40–50 people
☐ 50–60 people
☐ other (please fill in the specific number): _____

13. It is

☐ Elective courses
☐ Compulsory courses

14. The main teaching methods you use (multiple choices):

☐ Classroom lectures
☐ Group cooperative learning
☐ Self-learning
☐ Group modeling
☐ Case studies
☐ Other: _____

15. Teaching materials (multiple choices):

☐ Self-compiled lecture notes
☐ Self-compiled teaching materials
☐ Foreign teaching materials

16. If foreign teaching materials is used, what its proportion in your SD teaching?

☐ Very large
☐ Large

- ☐ Moderate
- ☐ Small
- ☐ Very small
- ☐ None

17. How satisfied are you with the overall teaching effectiveness of the course?

- ☐ Very satisfied
- ☐ Satisfied
- ☐ Neutral
- ☐ Dissatisfied

18. How satisfied are the students with this course?

- ☐ Very satisfied
- ☐ Satisfied
- ☐ Neutral
- ☐ Dissatisfied

19. In your opinion, what are the main benefits for students learning the SD (multiple choices)?

- ☐ Critical thinking ability
- ☐ Modeling ability
- ☐ Participation in academic competitions
- ☐ Paper publication

20. What are the main problems and difficulties you have found in your teaching (multiple choices)?

- ☐ Teacher team building
- ☐ Insufficient support from the school
- ☐ Insufficient funds
- ☐ Lack of course platform construction
- ☐ Unsatisfactory effect in practical application
- ☐ Teachers are concerned that Intellectual property rights cannot be guaranteed
- ☐ Students are not interested
- ☐ Lack of appropriate teaching materials
- ☐ Other: _____

21. In your opinion, does teaching SD help to promote you and your team's related academic research?

- ☐ Very helpful
- ☐ General effect
- ☐ No effect

22. In what areas do you hope that SD International Society and China Chapter can provide services (multiple choices)?

- ☐ International cooperation research
- ☐ Provide training courses
- ☐ Organize modeling competitions
- ☐ Opportunities for a cooperative degree program
- ☐ Literature and material acquisition
- ☐ Academic conference support
- ☐ Others:_____

23. What is the greatest experience in teaching the SD course? Can you share your teaching experience?
24. In what areas do you think can be improved in SD teaching?

According to your knowledge, which domestic universities/research institutes, etc., or who is also teaching SD-related courses? Can you help us forward the questionnaire? Thank you!

Appendix B. GMB Session Scripts

(5 min)

1. Introduction of the objective, team composition and division of tasks for the GMB session.

Objective: The objective of the workshop is to work with the identified experts to uncover the causal relationships that led to the results presented in the survey. By searching for suitable experts from the expert database of the System Dynamics (SD) Technical Committee, China Systems Engineering Society, to distribute and analyze questionnaires (already completed), we have gained a clear direction for further research on SD education in China. Therefore, we plan to use the GMB method for a deeper investigation.

Team Composition and Task Division: There are a total of 8 participants, including 2 coordinators—one responsible for the overall session progress and summary of issues, and the other in charge of constructing the Causal Loop Diagram (CLD) and addressing matters related to video conference software voting, etc.; the other 6 experts are 5 professors and 1 lecturer, among whom 3 are vice-chairpersons of the SD Technical Committee, and 3 are senior members with an average teaching experience of more than 15 years in SD.

(20 min)

2. First, understand each participant's individual inference on the overall development of SD education in China. Each of you is invited to share your hopes and fears regarding the development of SD education in China. You can list many understandings that you consider important, and please explain why you have such hopes and fears. During the explanation process, you can discuss and continually revise your thoughts and views.

(10 min)

3. Based on the prior discussions, each participant should list what they believe are the most important hopes and fears (3-4 of each, and share them with the host). The coordicator will set up the voting function in the Tencent meeting, and vote on the collected most important hopes and fears. If there is a significant disagreement in the results of a round of voting, multiple rounds can be conducted until consensus is reached on the most important hopes and fears.

(10 min)

4. Regarding the agreed-upon hopes and fears, each member is asked to share how they believe these hopes and fears should be measured. Please each draw a diagram with the Y-axis defined by you to show the behavior. The X-axis is the timeline, with the present moment as the dividing line—what was the behavior before the present moment and what will it be after? This will form the reference mode of this study.

(20 min)

5. Design effective intervention policies for the future development of SD education, considering the policy's impact on the reference mode. Please brainstorm to find all possible key influencing variables, and then select 10-15 important variables as the basis for subsequent CLD construction.

(30 min)

6. In a free discussion format, communicate thoroughly and attempt to find key loops among the important variables, gradually constructing a complete CLD.

(20 min)

7. Identify potential leverage points and action plans for policy analysis by looking at the loops in the CLD that may have a significant impact on the reference mode.

8. After the first round of modeling is completed, the model will be sent to each participant for correction and feedback. If necessary, we will conduct another round of GMB.

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