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Prospective Science Teachers' Views on Socio-Scientific Issues: A Mathematical Modeling Study

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ABSTRACT
The rapid changes in the world and the difficulties in accessing accurate information increase the need for individuals to engage in analytical and mathematical thinking. Therefore, educational reforms are being implemented, offering various approaches, including mathematical modeling. Mathematical modeling, which enables individuals to evaluate real-life situations using mathematical expressions, has recently been extensively studied in mathematical education but not science education. In this research, the topic of genetically modified organisms, a socio-scientific issue as a real-life situation, has been addressed. Sixteen prospective science teachers from a state university in the Marmara Region of Turkiye participated in the study. The "Genetically Modified Product Production" model eliciting activity developed by researchers was used as the data collection tool. The modeling activity aims to determine the prospective science teachers' levels of mathematical modeling and their views on the production of genetically modified products. The data obtained from the research were analyzed using descriptive analysis methods. As a result of the research, although the participants encountered this activity for the first time, they generally demonstrated modeling competencies at Levels 2 and 3 (sufficient and moderate) in their solutions to the modeling activity. Regarding the production of genetically modified products, participants mainly expressed opposing views, considering it a socio-scientific issue.

Keywords: *socio-scientific issues, genetically modified organisms, mathematical modeling competencies*

INTRODUCTION

Rapid changes worldwide are causing continuous evolution in educational systems by increasing the demand for knowledge. This transformation and development shape education to impart knowledge and enable the practical application of acquired knowledge, its integration into life, and adaptability to new situations. The Programme for International Student Assessment (PISA) is an investigation conducted in line with these objectives, measuring students' science, mathematics, and reading skills across countries (Dinç, 2020). After the results, Turkiye participated in PISA in 2003 and changed its education program. Mathematical modeling studies that promote students' analytical thinking and focus on real-life problems stand out in this context.

The model is the whole of conceptual structures existing in the thought system to understand and interpret complex structures and systems and their outward appearances (Doruk, 2010). On the other hand, modeling eliminates the problem situation existing in real life (Sandalcı, 2013). It can be said that modeling is a process that contributes to forming the model, preparing the necessary ground for the model to form. Mathematical modeling is an effective method that enables us to see the relationships within the problems of daily life, classify these relationships from a mathematical perspective, explain and generalize them, and derive conclusions (Fox, 2006). This research addresses genetically modified organisms as a socio-scientific issue, representing a real-life problem.

Genetically Modified Organisms (GMOs) obtained through modern biotechnological methods involving gene transfer are a widely debated topic in society to meet the food demand resulting from increasing population growth (Orhan, 2022). While GMOs can yield more resistant crops, have higher nutritional value, longer shelf life, improved taste and smell, and require fewer agricultural chemicals, they also have the potential to increase meat, milk, and wool production in animals (Kaynar, 2009; Ergin and Yaman, 2013). However, GMOs also raise various concerns within society, including threats to biodiversity, the creation of antibiotic-resistant bacteria, allergic reactions, as well as toxic and carcinogenic effects, alongside their religious implications (Uzogora, 2000; Craig et al., 2008). This dilemma has influenced both individual consumption choices and the decisions made by countries regarding their agricultural, livestock, and trade policies. While GMO farming is practiced in 29 countries, including the United States, Brazil, and Canada, European Union (EU) member countries have chosen a cautious approach to the issue. In Turkiye, while the production and consumption of GMOs as food are not permitted, their use as animal feed is regulated under various conditions (Official Gazette of the Republic of Turkiye, March 26, 2010, No: 27533; Official Gazette of the Republic of Turkiye, August 13, 2010, No: 27671). Despite being science and technology-centered, issues like GMOs do not gain widespread societal acceptance due to various dilemmas they encompass. These topics, known as Socio-Scientific Issues (SSI), contain multiple dimensions and are not universally accepted within society (Fleming, 1986; Patronis et al., 1999; Zeidler et al., 2002).

This research aimed to determine the perspectives of 16 prospective science teachers studying at a state university in Turkiye during the 2023-2024 academic year regarding genetically modified organisms, a socio-scientific issue. For this aim, mathematical modeling was employed. Mathematical modeling studies enable the integration of real-life contexts, thereby being applied and utilized in the fields of science and mathematics, assisting in their interrelation (Dinç, 2020). Mathematical modeling is a process of creating a model and is also defined as a two-way transformation process between the real world and the world of mathematics (Blum and Borromeo Ferri, 2009).

The following research questions have been explored in line with the research purpose:

1. What are the modeling competencies of prospective science teachers during the solution process in the "Genetically Modified Product Production" model eliciting activity?
2. What are the socio-scientific perspectives of science teacher candidates regarding Genetically Modified Organisms (GMOs) in the context of the "Genetically Modified Product Production" model eliciting activity?

METHODOLOGY

The research was designed as a qualitative research method, specifically a case study (Yin, 2018), to demonstrate prospective science teachers' mathematical modeling competencies and examine students' views on genetically modified organisms with a holistic perspective. Case studies are defined as a method where one or more events, social groups, environments, or programs are thoroughly examined, evaluated, or explanations are developed regarding an event (McMillan, 2000). In this study, the participants' levels of mathematical modeling competence and their views on genetically modified products as socio-scientific issues were considered individual cases.

Participants of the Research

In qualitative research, the characteristics of individuals become significant in line with the subject being investigated. According to the research objectives, a non-probability sampling method, specifically the purposive sampling method (Patton, 1987), was suitable for a case study approach. The study group of the research consists of 16 prospective science teachers studying at a state university in a province located in the Marmara Region of Turkiye. Per ethical principles, the names of the participants in the study group have been anonymized and denoted as P1, P2, P3, … P16.

The Data Collection Tool

The data collection tool for the research is the Genetically Modified Product Production Model Eliciting Activity (Appendix 1), which the researchers developed. The data collection tool and assessment rubric were finalized based on input obtained from an associate professor specializing in mathematics education with expertise in mathematical modeling and teaching in this field and an associate professor specializing in socio-scientific issues and teaching in this domain within science education. Their expert opinions were incorporated to shape the final version of the data collection instrument and the evaluation rubric.

Analysis of the Data

Model eliciting activities were developed by adhering to the principles of modeling practices outlined by Tekin Dede and Bukova Güzel (2014). These principles encompass an introductory article, readiness questions, a problem scenario, and the presentation of solutions. The theoretical framework of the modeling cycle developed by Borromeo Ferri (2006) under the cognitive perspective was chosen. Under this cognitive perspective, cognitive modeling competencies consist of the following stages: understanding the problem, simplification, mathematization (transforming it into a mathematical model and working mathematically), interpretation, and validation. Specific sub-questions were posed to teacher candidates along with the given activity to assess these mathematical modeling competencies. These questions are as follows:

1. *Express the problem in your own words.*
2. *Explain the information you need to solve the problem.*
3. *Describe the mathematical approach you will take to solve the problem.*
4. *Write down the appropriate operations to solve the problem.*
5. *Do you think the solution you found is appropriate? Explain with reasons.*
6. *How can you ensure the accuracy of the solution you found? Explain.*

In addition to these questions, an extra question has been added to gather the opinions of prospective science teachers regarding genetically modified organisms, a socio-scientific topic, numbered as the 7th question. The question is as follows:

7. *Do you think genetically modified products should be produced in our country? Please provide a detailed explanation of your thoughts on this matter.*

The rubric presented below was used to assess the participants' mathematical modeling competencies.

Table 1. Modeling Competencies Rubric

Skill	Levels	Description	Point
Understanding the problem	Level 1	Failure to include expressions indicating a lack of understanding of the problem, inability to identify given information and what is required, and failure to establish relationships or establishing incorrect relationships.	0
	Level 2	Including expressions indicating a complete understanding of the problem and the ability to identify given information and what is required, yet being unable to establish relationships or establishing incorrect relationships.	1
	Level 3	Including expressions indicating a complete understanding of the problem, identifying given information and what is required, and establishing an appropriate relationship among them.	2
Simplification	Level 1	Failure to simplify the problem, failure to determine necessary/unnecessary variables, making incorrect assumptions.	0
	Level 2	Partially simplifying the problem, partially determining necessary/unnecessary variables, but making incorrect assumptions.	1
	Level 3	Simplifying the problem, determining necessary/unnecessary variables, and making realistic assumptions.	2
Mathematization	Level 1	Failure to create a mathematical model or creating incorrect model(s).	0
	Level 2	Creating correct mathematical model(s) based on somewhat acceptable assumptions.	1
	Level 3	Creating necessary mathematical model(s) based on realistic assumptions, explaining the model(s), and correlating them with each other.	2
Interpretation	Level 1	Incorrect interpretation or no interpretation of the obtained mathematical solution in the context of real life.	0
	Level 2	Correctly interpreting mathematical solutions containing errors/omissions in the context of real life.	1
	Level 3	Correctly interpreting the correct mathematical solution in the context of real life.	2
Verification	Level 1	Failure to employ a verification approach or incorrect verification.	0
	Level 2	Partially/somewhat employing a verification approach, rectifying identified errors.	1
	Level 3	Employing a verification approach, rectifying identified errors.	2

In this research, the maximum score that can be obtained for each competency is three. The rubric used in this study aligns with the competencies within Borromeo Ferri's (2006) cognitive modeling perspective. This alignment exists because the competencies in the researcher-developed activities match those in Borromeo Ferri's cognitive modeling perspective. Therefore, this rubric was employed to assess modeling competencies in this study.

Content analysis has been conducted for the 7th question related to genetically modified organisms, a socio-scientific issue. Content analysis represents a research technique utilized for scrutinizing patterns evident within documented forms of communication, which may include texts, images, audio, or video. Social scientists rely on content analysis to systematically investigate and replicate patterns in communication (Bengtsson, 2016). This method entails a structured review or observation of texts or artifacts, where specific labels or meaningful elements within the content are identified and analyzed methodically (Dinçer, 2018). Two researchers independently evaluated participants' mathematical modeling competencies and content analysis.

Validity and Reliability of the Research

In validity studies within qualitative research methods, the concept of "credibility" is used instead of internal validity, and the concept of "transferability" replaces external validity (Lincoln & Guba, 1985).

Credibility

The research objective and its process were extensively articulated. The themes relevant to the responses of the participants involved in the modeling activity were vividly described, and the research process was meticulously recorded through observation and notes. Additionally, expert opinions were sought to construct the "Genetically Modified Product Production" modeling activity and the assessment rubric for mathematical modeling. Direct quotations reflecting the overall data were included while presenting the responses of fifth-grade elementary school students in this study.

Transferability

Due to the nature of the qualitative research and its divergence from generalization concerns, it is plausible to consider that similar results could be achieved when implementing the "Genetically Modified Product Production" modeling activity with a group of students akin to the study group under similar conditions. The data derived from participants' responses were analyzed according to steps and levels established by the developed rubric. The analysis process commenced after an initial holistic examination of the data.

Given that the study is a qualitative endeavor, it distances itself from concerns of generalization. Thus, regarding the reliability of the qualitative data, the notion emerges that "similar results could be obtained through conducting a similar study with a similar group under similar conditions" (Ergene, 2019; Uzun, Ergene, and Masal, 2023). Consequently, consensus was reached on solutions to form a collective agreement. The coder reliability in data analysis was calculated at 91% (Miles & Huberman, 1994).

Research Ethics

Throughout the entire process, from planning and execution to data collection and analysis, this research adhered to all rules stipulated within the "Regulation on Scientific Research and Publication Ethics of Higher Education Institutions." In the drafting process of this study, adherence to scientific, ethical, and citation standards was ensured. All participants voluntarily participated in the research. The collected data remained unaltered, and the study was not submitted for assessment in any other academic publication environment.

FINDINGS AND DISCUSSION

The findings of the research will be presented in two sections. First, the results obtained from the problem-solving processes of the prospective science teachers participating in the "Genetically Modified Product Production" modeling activity will be conveyed. Subsequently, participants' views about GMOs, a socio-scientific issue, will be discussed.

Findings Related to the "Genetically Modified Product Production" Model-eliciting Activity

This section presents the findings obtained from evaluating the solution papers of prospective science teachers in the "Genetically Modified Product Production" modeling activity within the mathematical modeling competencies framework. The solutions provided by participants for the mathematical modeling problem were analyzed considering each modeling competency.

Concerning the first mathematical modeling competency, which is understanding real-life problems, participants were expected to express the problem in their own words, identify given and required elements of the problem, and articulate the purpose of the problem. The findings related to the behaviors exhibited by participants for this competency are presented in Table 2.

Table 2. Distribution of Prospective Science Teachers' Competency in Understanding Real-Life Problems

Levels	Participants	f (%)
Level 1	P15, P16	2 (12, 6)
Level 2	P1, P3, P4, P5, P6, P7, P8	7 (43.7)
Level 3	P2, P9, P10, P11, P12, P13, P14	7 (43.7)

When examining Table 2, it was observed that a tiny fraction of the participants in the study (n=2, %12.6) did not express the problem in their own words and directly performed mathematical operations without determining the purpose of the problem. These students were identified as having Level 1 competency in understanding real-life problems. Seven participants (%43.7) did not express the problem in their own words; however, they partially identified the given and required aspects of the problem. Hence, these students were classified as having Level 2 competency in understanding real-life problems. The remaining portion (%43.7) clearly understood the problem, thereby categorized with Level 3 competency in understanding real-life problems.

In the second competency of mathematical modeling, which is simplifying the problem, participants are expected to distinguish between the variables of the problem and the necessary-unnecessary information for solving the problem. The findings related to the behaviors exhibited by science teacher candidates regarding this competency are presented in Table 3.

Table 3. Distribution of Prospective Science Teachers' Competency in Simplifying the Problem

Levels	Participants	f (%)
Level 1	P1, P15, P16	3 (18, 7)
Level 2	P3, P4, P5	3 (18, 7)
Level 3	P2, P6, P7, P8, P9, P10, P11, P12, P13, P14	10 (62, 6)

When examining Table 3, it was observed that a small fraction of the participants in the study (n=3, %18.7) couldn't simplify the problem, failed to distinguish necessary-unnecessary information, and couldn't make assumptions. These participants were identified as having Level 1 competency in simplifying the problem. However, it was determined that more than half of the participants were able to simplify the problem, and their competency level was determined as Level 3.

The third competency in mathematical modeling, which is mathematization, entails science teacher candidates creating a mathematical model, such as drawing graphs, constructing tables, and forming equations for the problem. The findings related to students' behaviors regarding this competency are presented in Table 4.

Table 4. Distribution of Prospective Science Teachers' Competency in Mathematization

Levels	Participants	f (%)
Level 1	-	0 (0)
Level 2	P15, P16	2 (12.5)
Level 3	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14	14 (87.5)

An interesting finding emerging from Table 4 in the research is that all science teacher candidates exhibit a certain level of competency in mathematical modeling. It is observed that almost all participants (87.5%) have a Level 3 competency in mathematical modeling, a tiny portion (12.5%) have Level 2 competency, and none (0%) are at Level 1.

In the competency of interpreting the problem within mathematical modeling abilities, prospective science teachers are expected to interpret the problem-solving obtained in the context of real-life situations. The findings related to participants' behaviors regarding this competency are presented in Table 5.

Table 5. Distribution of Prospective Science Teachers' Competency in Interpretation

Levels	Participants	f (%)
Level 1	P9, P13	2 (12.5)
Level 2	P1, P2, P3, P6, P14	5 (31.2)
Level 3	P4, P5, P7, P8, P9, P10, P11, P12, P13	9 (56.3)

When examining Table 5, it is observed that more than half of the prospective science teachers (56.3%) have a Level 3 competency in interpreting the problem, some (31.2%) are at Level 2, a tiny portion (12.5%) encounter challenges in interpreting the problem, classified as Level 1 competency.

The final competency in mathematical modeling, which is the ability to verify the problem, entails prospective science teachers questioning the suitability of their constructed mathematical model and the mathematical solutions obtained for real-life situations. The findings related to participants' behaviors regarding this competency are provided in Table 6.

Table 6. Distribution of Prospective Science Teachers' Competency in Verification

Levels	Participants	f (%)
Level 1	P2, P3, P9, P12, P13, P14	6 (37.5)
Level 2	P1, P4, P5, P6, P7, P8	6 (37.5)
Level 3	P10, P11, P15, P16	4 (25)

Table 6 indicates that prospective science teachers have a comparatively lower level of competency in verification than their proficiency in other ones. Some participants (37.5%) were unsure about the accuracy of their mathematical operations, another 37.5% were able to conduct partial verification, while only 25% managed to perform complete verification, demonstrating a Level 3 competency.

Findings Related to the SSI (GMOs)

In this study, prospective science teachers' views regarding the production of GMOs in Turkiye were also investigated. For this purpose, the responses to the question "*Do you think genetically modified products should be produced in our country? Please provide a detailed explanation of your thoughts on this matter*" were subjected to content analysis. A total of 26 codes were generated during the content analysis. These codes were categorized into themes and sub-themes, leading to the identification of themes and sub-themes as depicted in Figure 1. The analysis revealed that out of the 16 participants involved in the research, 2 expressed a positive perspective on the production of GMOs, while 14 conveyed an opposing viewpoint.

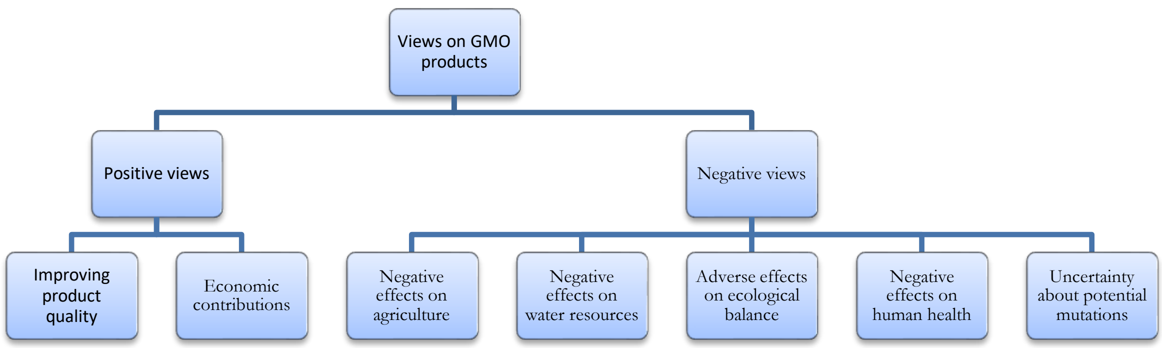

Figure 1. Themes and sub-themes related to the participants' perspectives.

GMO products supporters expressing positive views on GMO product production can be explained through two sub-themes: improving product quality and economic contributions. Participant P3 stated his/her opinion in favor of GMOs, mentioning, *"Ultimately, it will lead to the production of higher-quality products."* Both participants, P3 and P6, highlighted the contribution of

GMO product production to the country's economy. Participant P6 expressed, *"Because its contribution to the country's income can be quite significant. And as the country's population is increasing day by day, the country needs to recover economically."* Although participant P3 expressed a positive view on producing GMO products, they were aware of the potential risks to human health associated with GMOs. Therefore, they suggested that these products should be produced with reduced harmful effects on health.

Most participants (n=14) have expressed opposing views regarding the production of GMO products. A significant portion of these participants (n=10) indicated a negative perception of this production method due to its perceived risks to human health. For instance, participant P1 mentioned that GMO products might lead to cancer and allergic reactions, while participant P8 highlighted that besides health issues like obesity and diabetes at an early age, GMO products could also cause heart, vascular, and brain diseases. Participant P10 mentioned that GMO products might weaken the immune system and disrupt hormonal balance in individuals due to their potential allergens.

Three participants in the study addressed the harm caused to ecological balance by producing GMO products. For instance, participant P13 mentioned that GMO products have a negative impact on natural ecosystems and biological diversity. Similarly, participant P4 stated that GMO products contaminate water sources.

The three participants in the study addressed the harm caused by the production of GMO products in agriculture. Participants P1 and P4 mentioned that the development of pesticide-resistant insects harms agricultural crops due to GMO products. Participant P1 expressed his/her opinion: "*The pesticide-resistant insects caused by GMO products have a significantly negative impact on agriculture. I believe that impacting healthy farming is sufficient reason to keep this situation away from our country.*" Participant P13 expressed concerns that GMO product production could harm traditional agriculture and local farmers by stating, "*Considering the goal of preserving local agricultural culture and the use of traditional seeds, the effects of GMOs on local farmers and seed producers could lead to adverse consequences.*"

The P14 participant expressed a negative opinion due to the belief that there is insufficient knowledge regarding the mutations and potential harms that could occur due to GMO product production.

Despite 10 participants expressing opposing views on GMO product production, participants P5 and P9 are aware of the financial advantages of these products. However, they emphasized that these benefits should not be preferred over human health. Participant P9 vividly expresses this perspective: *"GMO is actually a nice, positive thing that would contribute to people. But because it has the potential to cause diseases in people... since health is the most important thing in life and GMO poses a danger to life, say no to GMO!"*

In this research, the mathematical modeling competencies of prospective science teachers and their opinions regarding genetically modified organisms, a socio-scientific topic, were examined based on their responses to the "Genetically Modified Product Production" modeling activity. The initial result obtained from the research pertains to the extent to which prospective science teachers understand the "Genetically Modified Product Production" problem, designed to correspond to real-life situations in line with the principle of reality. Regarding the first competency of mathematical modeling, which is the ability to comprehend real-life problems, it was concluded that participants did not encounter difficulties understanding real-life problem situations. This result differs from previous literature studies (Deniz and Yıldırım, 2018).

The second outcome derived from the research concerns the proficiency of prospective science teachers in the second aspect of mathematical modeling, namely, the simplification competence. It was observed that some participants had difficulties distinguishing between variables in the problem and discerning necessary and unnecessary information for solving the problem, resulting in the determination of their simplification competencies at Levels 1 and 2. However, a considerable portion possessed this competence. A successful mathematical modeling process relies on correctly comprehending and simplifying the problem (Lesh & Doerr, 2003). Many studies have indicated that students struggle with the initial competency of mathematical modeling, specifically in simplifying the problem (Blum, 2015; Karahan & Ergene, 2023). This issue might be attributed to a lack of components in students' problem-solving behavior, such as discussion or thorough thinking (Albayrak & Tarım, 2022).

The third outcome derived from the research relates to the mathematical modeling competence of prospective science teachers in terms of mathematization. Most participants accurately identified variables and demonstrated competence at Level 3 by correctly performing mathematical modeling. This finding differs from studies in the field (e.g. Blum & Borromeo-Ferri, 2009). It is assumed that the selection and use of appropriate variables directly impact the mathematization stage (Hıdıroğlu et al., 2014).

Mathematically, during the modeling stage, participants are expected to build a mathematical model and solve the problem using mathematical operations. Individually, participants were observed to construct a mathematical model aligned with their mathematical understanding of the given problem and perform mathematical operations relevant to this model (Doerr & English, 2003). It has been determined that the most challenging competency in the modeling process is the verification competence (Blum & Borremeo Ferri, 2009; Tekin Dede & Yılmaz, 2013). Consistent results with this finding have also been obtained in this research. In the fifth competency of mathematical modeling, which is the ability to interpret the problem, it was expected that prospective science teachers would interpret their obtained problem solutions in the context of real-life situations. It was observed that the majority of participants were able to interpret their mathematical results in real-life situations. However, it was noted that a significant portion of them were not confident about the accuracy of their models during the verification stage.

According to the literature mentioned, the mathematical modeling competency levels among prospective science teachers have been relatively high. Participants have observed that through modeling activities related to genetically modified products, their countries would obtain high incomes. Despite this, they have expressed opposition to the use of genetically modified products, emphasizing their adverse effects on humans and the environment. This result is consistent with the literature (Bawa and Anilakumar, 2013). According to the literature, people can perceive the potential economic benefits of genetically modified products, yet they may express concerns about the possible risks these products pose to human health and the environment. This situation reflects a similar trend among the participants.

CONCLUSION

The research findings indicate that prospective science teachers' mathematical modeling competencies are higher compared to previous studies. That result is believed to be due to prospective science teachers engaging in mathematical modeling on socio-scientific issues. Further studies involving prospective science teachers in this field are recommended.

The research findings indicate that prospective science teachers have high mathematical modeling competencies, while their opinions regarding cultivating genetically modified products tend to be generally negative. This situation is valuable as it demonstrates the importance prospective teachers place on human, societal, and environmental health.

The topic of mathematical modeling is under-explored within the field of science education. Specifically, there is a lack of studies on socio-scientific issues within the scope of mathematical modeling. Mixed-method research designs utilizing quantitative and qualitative data collection tools could lead to more meaningful and comprehensive findings in this field.

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