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Analysis of high school students' scientific modelling ability measures and their impact pathways

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ABSTRACT

In today's world, technological advances are rapidly changing, new media are rapidly becoming popular, people's ways of living, learning and working are constantly changing, the environment in which young people grow up is profoundly changing, talent training is facing new challenges, and it is imperative to optimise the blueprint for educating people in schools. As the basis for scientific reasoning, scientific argumentation and questioning and innovation, the ability to construct physical models occupies an important position in scientific thinking skills. The study found that: high school students' scientific modelling skills are currently at a low level, with the ability to "test and revise models" in need of strengthening; students' performance in science is correlated with their scientific modelling skills, with a direct and significant impact of learning emotions on students' scientific thinking. Both "science practice" and "teacher teaching" can indirectly improve students' scientific modelling skills through learning emotions. It is suggested that teachers should focus on students' interest in learning, introduce STEAM mode of teaching, and increase the frequency of scientific practice in order to improve students' scientific modelling ability.

1.Introduction

In today's world, technological advances are rapidly changing, new online media are rapidly gaining popularity, the way people live, study and work is constantly changing, the environment in which young people grow up is profoundly changing, talent training is facing new challenges and it is imperative to optimise the blueprint for educating people in schools. in March 2014, the Chinese Ministry of Education released the document "Opinions of the Ministry of Education on Comprehensively Deepening Curriculum Reform and Implementing the Fundamental Task of Establishing Moral Education", which states: "Students are equipped with the necessary qualities and key competencies to adapt to the needs of lifelong development and social development, and to develop their core literacy." In order to more comprehensively implement the cultivation of core literacy in physics, and to further clarify "what, how and for whom to cultivate", the Physics Curriculum Standards for Compulsory Education (2022 Edition) issued by the Chinese Ministry of Education clearly states the content of core literacy in physics, namely The four areas of "physical concepts", "scientific thinking", "scientific investigation" and "scientific attitudes and responsibilities". The GCSE Physics Curriculum Standards (2017 Edition Revised 2020) classifies model building into five levels: be able to name some simple physical models ➡ be able to apply common physical models in familiar problem situations ➡ be able to choose appropriate models to solve simple physical problems as needed in familiar problem situations ➡ be able to convert objects and processes in real problems into physical models ➡ be able to convert more complex convert objects and processes in more complex real-world problems into physical models (Ministry of Education of the People's Republic of China,2017). "Model building" is part of the "scientific thinking" physics core literacy, and is an important part of the physics core literacy. Model-building skills refer to the process of constructing physical models based on empirical facts and abstraction of basic physics knowledge, and require students to be able to use the models they have learned to solve common physics problems. As the basis for scientific reasoning, scientific argumentation, and questioning and innovation, the ability to construct physics models occupies an important position in scientific thinking skills, but research shows that compared to the high level of attention paid to modelling education research abroad, China's physics modelling education research is slightly insufficient and empirical research is lacking (Zhai&Guo,2015). Therefore, it is necessary to understand and measure students' physics modelling skills and to develop them in a targeted manner. Based on the above, this research team developed a set of scientific thinking assessment questions and collected some background information from students in an attempt to investigate the current situation of high school students' scientific modelling ability and its influencing factors, and to provide some reference for front-line teachers' teaching.

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2.Research Methodology

2.1 Participants and assessment tools

In order to test the validity of the proposed assessment tool, this study took the junior high school of a model secondary school in Zhejiang Province as the experimental school. 381 students were randomly selected from the junior high school as the test subjects, and a total of 381 test papers were collected, excluding 9 invalid test papers (unanswered or large blank), resulting in a total of 372 valid questionnaires, with an effective rate of 97.63%. This secondary school has a rich student population and excellent teaching quality, and there are some differences between student groups. At the time the assessment study was conducted, the students tested had already completed all the physics knowledge covered in the test questions and could be used as the subjects of this test.

Data for this study were obtained through standardised science examinations, scientific thinking test papers and questionnaires. Science examinations were used to collect students' performance in science. The question papers were prepared by subject experts invited by the higher education authorities and provided with uniform reference answers, thus having good expert reliability. The papers are percentage-based and are marked and verified collectively by a number of physics teachers, so they have good consistency. The Scientific Thinking Test is used to collect information on the level of scientific thinking of students. The development process of the test paper is as follows: (1) the questions used to examine scientific thinking were selected from the 2019-2022 secondary school physics test papers collected from the official websites of the four major examination centres in the UK and the education websites of the 50 states in the US; (2) the questions were categorised and aggregated according to the knowledge points examined to filter out the high frequency test points; (3) the high frequency test points were compared with the high school physics curriculum standards to filter out the overlap of knowledge points After four rounds of discussions between the Physics Education Expert Group and frontline teachers, the topic of "Circuits" was selected; (4) three context-based scientific thinking skills tests were selected under the "Circuits" knowledge point and adapted to form a scientific modelling test that examined three dimensions: model construction and use, model testing and revision, modelling metacognition and metamodelling knowledge, with three questions in each dimension and nine items in total. The final questionnaire was discussed in four rounds by a panel of physics education experts and frontline teachers to ensure its scientific validity and standardisation.

The content of the background questionnaire mainly includes several aspects of science subject identity, science practice, teacher teaching, learning quality, learning emotion and learning behaviour. To ensure that the scale questions in this questionnaire are stable and valid, the SPSS 26.0 software was used to test the reliability of all the questions in the questionnaire. The overall CloneBart alpha value was 0.799, which has good reliability. The common factors drawn from the exploratory factor analysis were able to explain 66.414% of the variance cumulatively, and the factor loadings were all greater than 0.6, giving the questionnaire good structural validity.

2.2Quality of scientific thinking assessment tools

In the Rasch model measure, the test instrument was analysed using Winstep software and the main parameters included in the reliability dimension were subject reliability (0.81), test item reliability (0.95), subject differentiation (2.57) and test item separation (4.24). The reliability analysis was also carried out using SPSS and the Cronbach's alpha was 0.799. It can be seen that the reliability of the evaluation instrument performed well, indicating that the subjects in this study performed well in terms of the reproducibility of the test variables and item distributions, and that there was a good degree of separation between the subjects' ability and test difficulty on the measured variables, allowing for the differentiation of different subjects' abilities. The main parameters of the Rasch model are the unidimensionality of the test items, the fit of the test items, and the rating scale structure of the test items. The unidimensionality of the questions reflects whether the items in the test instrument are able to examine the same level of ability of the subject, and most of the dimensions in this test instrument fall between -0.4 and 0.4, which meets the unidimensionality requirement. For the Infit and Outfit indicators of data-model fit, the values of the ZSTD for each item ranged from -2.3 to 2.0, the parameter values of the MNSQ ranged from 0.75 to 1.31, and the values of the point measurement correlation (PT-MEASURE CORR.) all ranged from 0 to 1, indicating a good fit between the actual data of the test questions and the model. The actual data from the test questions fit the model well. The rating scale category curves for each dimension of the test have clear peaks and are straight and cover a range of horizontal coordinates, which is good. The results of the reliability test of the test instrument are shown in Table1, indicating that the scientific reasoning instrument designed in this study can effectively measure the scientific reasoning ability of the subjects.

Table1 Results of the reliability test of the Scientific Thinking Test instrument

Indicators	Test results
Credibility	Subject reliability: 0.81 Reliability of test questions: 0.95 Cronbach's alpha was 0.799
Separation	Subject separation: 2.57 Separation of test questions: 5.99
Unidimensionality of test questions	Most topics fall between -0.4 and 0.4 , which meets the unidimensionality requirement.
Test question fit	The actual test data fit the model well
Test marking scale structure	Good

2.3 Characteristics of students' scientific thinking

Wright diagram (Figure1) provides information about the distribution of item difficulty matched to the ability level of the subjects.The Wright diagram lists the positions of 372 students and 9 items on a generic scale. The Wright plot examines the relationship between item difficulty and test taker ability level. The left-hand portion of the plot shows the distribution of subject ability levels, with the leftmost number being the logit unit of subject ability and item difficulty, and the right-hand side showing the distribution of item difficulty, with student ability and item difficulty decreasing in order from top to bottom. Each "#" represents four students and each "." represents one to three students. The results showed that the range of ability levels was larger than the difficulty distribution of the test questions, with the highest ability being 4.80 logit, the lowest being -4.65 logit, and the highest number of subjects with an ability of -0.54 logit being 46. The distribution of scientific modelling ability levels was wide, with significant differences, and was basically normally distributed. The range of difficulty of the questions was about 1.47 logits, with the first question "model testing and modification" being the most difficult at 0.86 logit and the second question "model metacognition and metamodelling knowledge" being the easiest at -0.61 logit. The mean value of the subjects' ability was -1.16 logits and the mean value of the difficulty of the questions was 0.00 logits, which means that t the subjects' scientific reasoning ability is at a moderate to low level.

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Figure1 Wright diagram

3.Level of performance of students' scientific thinking skills

3.1 Overall performance of scientific thinking skills

The overall scientific modelling competency is shown in the table below. The scientific modelling competency was tested by three questions, each containing three secondary indicators of model construction and use, model testing and revision, and modelling metacognition and metamodelling knowledge, with a total of nine items. The overall scientific modelling mean score was 0.67, with model construction and use at 0.67, model testing and revision at 0.55, and modelling metacognition and metamodelling knowledge at 0.76, with the highest scores for the modelling metacognition and metamodelling knowledge dimensions and the lowest scores for the model testing and revision dimensions.

	Tier 1 indicators	Secondary indicators	Minimum	Maximum	Average (standard deviation)
Scientific modelling	Question 1	Model construction and use	0.00	2.00	0.66 (0.72)
		Model testing and correction	0.00	2.00	0.58 (0.55)
		Modelling metacognition and metamodelling knowledge	0.00	2.00	0.71 (0.77)
	Question 2	Model construction and use	0.00	2.00	0.66 (0.73)
		Model testing and correction	0.00	2.00	0.55 (0.70)
		Modelling metacognition and metamodelling knowledge	0.00	2.00	0.86 (0.63)
	Question 3	Model construction and use	0.00	2.00	0.68 (0.89)
		Model testing and correction	0.00	2.00	0.52 (0.67)
		Modelling metacognition and metamodelling knowledge	0.00	2.00	0.82 (0.67)
Scientific modelling		Model construction and use	0.00	2.00	0.67 (0.57)
		Model testing and correction	0.00	2.00	0.55 (0.44)
		Modelling metacognition and metamodelling knowledge	0.00	2.00	0.80 (0.50)
Scientific modelling			0.00	2.00	0.67 (0.44)

Table2 Descriptive statistics of students' scientific thinking performance

3.2 Sub-dimensional representation of scientific thinking skills

To further characterize the specific performance of subjects' scientific modeling ability in different topics , Descriptive statistics (Table 3) and score rate calculations were done on nine items of scientific modeling ability in this study (Figure2). The descriptive statistics for each dimension of scientific modelling competency showed that students scored highest in each question for the dimension of "modelling metacognition and metamodelling knowledge", followed by the dimension of "model construction and use" and the dimension of "model The "Testing and Revision" dimension scored the lowest.

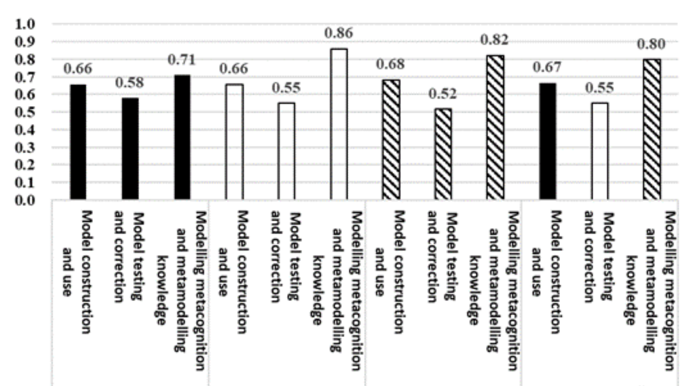

Figure2 Mean distribution of students' scientific modelling performance

3.3 Level distribution of scientific modelling capabilities

Based on the difficulty of the test questions, students' modelling ability levels were divided into three levels, Level 0, Level 1 and Level 2, in increasing order of difficulty. This indicates that most students are at Level 0 and Level 1, while only a small number of students reach Level 2. The highest percentage of students at Level 1 was 46.24% for "Modeling metacognition and metamodeling knowledge", while the percentage of students at Level 2 for both "Model revision and testing" and "Model construction and use" was The lowest level 2 of "model revision and testing" was 8.33%.

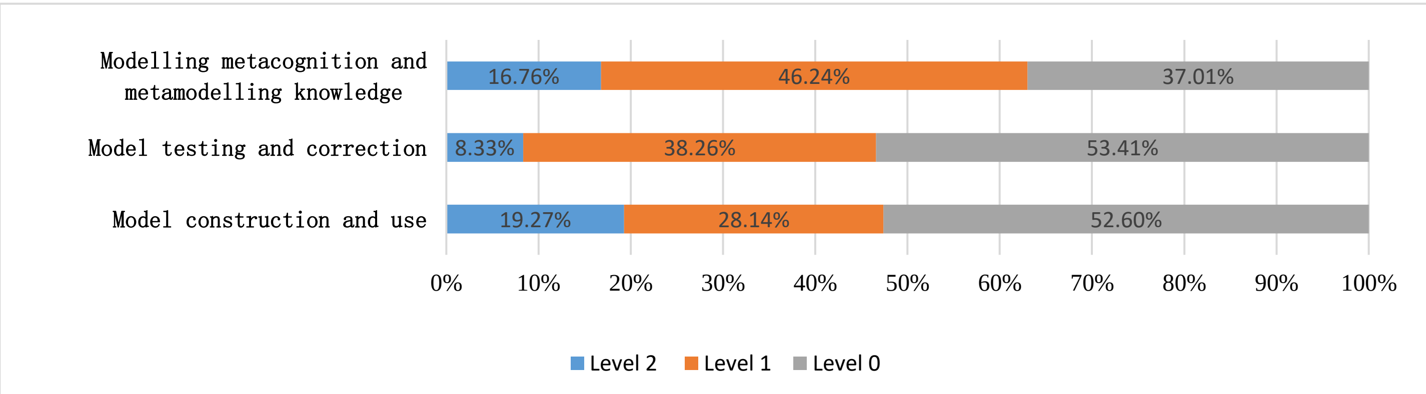

Figure3 Percentage distribution of students' performance levels in scientific thinking

4.Path analysis of factors influencing students' scientific modelling ability

4.1 Theoretical basis for path mapping

In order to investigate which factors significantly affect scientific modelling ability, this study investigated students' background factors such as science subject identity, science practices, teachers' teaching styles, learning qualities, learning emotions and learning behaviours, and developed hypotheses based on previous researchers' findings to build a model based on this data.

Li Qiong (2011) explored the influence of teachers' teaching styles on students' learning habits. Many overseas studies have shown that teachers' teaching styles affect students' learning adjustment (including academic performance, learning attitudes, teacher-student relationships and other aspects), and that if teachers can choose an appropriate teaching style for students' characteristics, they can not only enhance students' interest in learning, but also improve students' learning quality substantially (Martinez, 2000). Based on this, this study proposes the hypothesis that (1) teachers' teaching styles influence students' learning quality, learning emotions and learning behaviour.

In 1925, Tao Xingzhi, taking into account China's educational situation, put forward the theory of "teaching and doing in one"(Liu&Tang,2008). The word "doing" refers to doing, meaning a broad range of practical activities. Under the guidance of this theory, the Outline of Basic Education Curriculum Reform promulgated by China in 2001 clearly states that it is necessary to "change the status quo of over-emphasis on receptive learning, rote learning and mechanical training, advocate active participation, willingness to investigate and diligence in doing, and cultivate students' ability to collect and process information, acquire new knowledge, analyse and solve problems, and communicate and cooperate. The study will also develop students' ability to collect and process information, acquire new knowledge, analyse and solve problems, and communicate and cooperate (Anonymous,2002). Therefore, the hypothesis of this study is that practical science activities influence learning behaviour, learning emotions and learning quality

Subject identity, also known as professional satisfaction, is an indicator of a positive psychological state that creates a positive mood, increases one's sense of control and stability in academic life, and provides students with a high sense of self-worth (Reschly, Huebner, Appleton, Antaramian, 2008).

Some scholars have found that professional satisfaction and achievement per student show a mutually reinforcing relationship (Nauta, 2007).]

Learning qualities include self-efficacy and learning strategies. Wiser and Riggio (2010) investigated whether self-efficacy moderated the relationship between family background and academic achievement and found that self-efficacy was a strong predictor of academic achievement. Fast, Lewis and Bryant (2010) investigated the relationship between classroom environment, mathematics self-efficacy and academic achievement and found that high mathematics self-efficacy positively predicted students' mathematics achievement. Therefore, hypothesis (3) is proposed that science subject identity and learning qualities influence student achievement in science.

The relationship between scientific modelling skills and academic achievement has been a hot topic in educational research. Schwartz in 2014 investigated the learning of evaporation and condensation through scientific modelling in 34 fifth graders (age 10) in the United States. It was demonstrated that some aspects of modelling practice were more in line with typical school norms and practices than others, and that the development of scientific modelling skills could be effective in improving students' understanding of science in order to improve their academic performance in science (Hokayem &Schwarz ,2013). Therefore, hypothesis 4 is proposed that scientific modelling skills influence student achievement in science.

4.2Correlation analysis of study variables

The seven variables of science subject identity, science practice, teacher teaching, learning quality, learning emotion, and learning behaviour were analysed for correlation and the results are shown in Table3, which shows that there is a combined positive correlation between the variables and that the criteria for constructing a structural equation model are present.

Table3 Statistical and correlation analysis of the study variables

	Modelling capabilities	Scientific achievements	Scientific disciplinary identity	Science in Practice	Teacher Teaching	Learning Quality	Learning about emotions	Learning behaviour
Modelling capabilities	1							
Scientific achievements	.552**	1						
Scientific disciplinary identity	.200**	.286**	1					
Science in Practice	.105*	.116*	0.099	1				
Teacher Teaching	.195**	.200**	0.018	.164**	1			
Learning Quality	.222**	.275**	.135**	.366**	.377**	1		
Learning about emotions	.311**	.335**	.444**	.164**	.245**	.350**	1	
Learning behaviour	.154**	.200**	.131*	.378**	.318**	.481**	.253**	1

Note: N=372; ** indicates p<0.01, * indicates p<0.5, significant correlation

4.3Path test results

The results of the exploratory factor analysis carried out for all items in this study using the Harman one-way test showed that four factors had an eigenroot value greater than one and that the first factor explained 33.109% of the total variance, which was below the critical value criterion of 40%, indicating that there was no common method bias in this study.

This study used AMOS 24.0 for structural equation modelling to first test the index of model fit, which had a chi-squared =1.725 < 3, indicating a good overall fit. Rmsea =0.045 < .08 indicated a good fit, PNFI =0.355 < .5, GFI =0.985 ＞ 9, AGFI=0.953>.9, indicating that both the canonical fit index and the goodness-of-fit index were met.

Table4 Model test results

			β	S.E.	C.R.	P
Learning about emotions	**<--**	**Teacher Teaching**	.207	**.072**	**3.840**	***
Learning behaviour	**<--**	**Teacher Teaching**	.220	**.065**	**4.330**	***
Learning behaviour	**<--**	**Science in Practice**	.340	**.042**	**6.867**	***
Learning about emotions	**<--**	**Science in Practice**	.107	**.046**	**2.053**	**.040**
Learning Quality	**<--**	**Science in Practice**	.140	**.047**	**3.024**	**.002**
Modelling capabilities	**<--**	**Learning about emotions**	.264	**.259**	**5.176**	***
Learning Quality	**<--**	**Teacher Teaching**	.171	**.072**	**3.687**	***
Learning Quality	**<--**	**Learning behaviour**	.366	**.057**	**7.712**	***
Learning Quality	**<--**	**Learning about emotions**	.214	**.052**	**4.795**	***
Scientific disciplinary identity	**<--**	**Learning about emotions**	.426	**.053**	**8.721**	***
Scientific achievements	<--	Science in Practice	-.024	1.122	-.492	.623
Scientific achievements	**<--**	**Modelling capabilities**	.399	**.253**	**8.094**	***
Scientific achievements	<--	Learning about emotions	.034	1.422	.613	.540
Scientific achievements	**<--**	**Learning Quality**	.113	**1.264**	**2.000**	**.045**
Scientific achievements	**<--**	**Scientific disciplinary identity**	.130	**1.205**	**2.572**	**.010**
Scientific achievements	<--	Learning behaviour	.034	1.492	.608	.543

The results of this analysis show that teachers' teaching style has a significant positive effect on learning quality, learning affect and learning behaviour at the 0.001 level, with standardised path coefficients of 0.174, 0.207 and 0.22 respectively.

Using a scientific approach to teaching and guiding students to use scientific thinking to solve problems can increase students' interest and motivation in science subjects, as well as develop students' self-monitoring skills, promote the appropriate use of learning resources and increase their sense of efficacy. Hypothesis 1 was tested.

The frequency of students' participation in science and technology activities (e.g. making science and technology products, visiting science museums, etc.) significantly and positively improves students' performance in all aspects of learning science, confirming hypothesis 2.

Learning quality and science subject identity had a significant positive effect on science performance at the 0.05 level, with quantified path coefficients of 0.113 and 0.130 respectively, indicating that students who are able to use learning strategies effectively in their studies, have a high level of self-efficacy and are satisfied with their science subject are more likely to achieve better results in science academic examinations. The results of this analysis confirmed hypothesis 3.

Scientific modelling skills had a significant positive effect on science achievement at the 0.01 level, with a standardised path coefficient of 0.399 respectively, suggesting that students with higher scientific modelling skills who construct models to solve problems when faced with complex scientific scenarios are more likely to excel in science academic examinations validating hypothesis 4.

5.Discussion and Insights

5.1 High school students' scientific modelling skills are at a low level, Implement teaching methods to further improve students' scientific modelling skills

The results of the study show that most students' scientific modelling skills are at a low level of 0 and 1, and that overall students' modelling skills are low, even in the dimension of 'modelling metacognition and metamodelling knowledge', where the score is only

28%, indicating that high school students' scientific modelling skills are in need of improvement, especially in the area of problem solving by modifying the basic model according to the actual situation. This indicates that high school students need to improve their scientific modelling skills, especially in the area of problem solving by adapting basic models to real world situations. Therefore, frontline teachers need to pay attention to students' scientific modelling skills and provide tailored instruction for students' specific situations. Firstly, the scientific models that students learn in science classrooms are very limited and the ability to create and use integrated models in complex problem situations must be developed in order to improve students' modelling skills (Cai&Cai,2004). Secondly, modelling should be based on students' existing knowledge structures, and teachers should create specific life situations that are appropriate to students' cognitive structures, and take the initiative to guide students to construct and revise their own scientific models (Feng,2014).

5.2 Focus on the impact of science subject identity on scientific thinking skills, with emphasis on teacher-student relationships, teacher teaching and attitudes towards science learning

The results of the model showed a direct and significant positive effect of 'learning emotions' on students' scientific modelling ability, i.e. the stronger the students' tendency to recognize and research to gain scientific knowledge, the higher their scientific modelling ability. For high school students, making students aware of the importance of physics is a direct way to increase their interest in learning (Kim,1998). In addition, teachers can also stimulate students' interest in learning through the introduction, the design of the board, the classroom atmosphere, the teaching materials and methods, teaching aids, the use of multimedia, and the teacher-student relationship (Yu,2012).

The model also shows that hands-on science activities and teachers' teaching styles have a significant positive effect on 'affective learning'. Therefore, increasing the frequency of hands-on science activities and creating inquiry-based classrooms are also effective ways to improve students' scientific modelling skills. Firstly, experimental teaching contributes to students' understanding of science, their ability to investigate science and their interest in learning science(Wang&Lin,2021). Science teachers pay more attention to developing students' emotional attitudes towards science and experimental skills, etc. Front-line teachers should implement experimental teaching, optimise teaching design, develop students' emotional attitudes towards science and experimental skills, and schools should improve the hardware and software conditions for experimental teaching according to the actual situation. Secondly, surveys show that students in the middle and upper grades have an adequate knowledge base, a strong interest in practical activities, and an awareness of the close relationship between science and life, with the upper grades also having some experience in engineering and technology(Wang,2022). Teachers can improve students' scientific modelling skills by implementing STEAM teaching models from both a macro perspective and practical classroom moderation, with the practical aim of promoting students' development, and by enriching the form and frequency of students' practical science activities.

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