



# The Effects of Scientific Self-efficacy and Cognitive Anxiety on Science Engagement with the “Question-Observation-Doing-Explanation” Model during School Disruption in COVID-19 Pandemic

Xiantong Yang<sup>1</sup> · Mengmeng Zhang<sup>2</sup> · Lingqiang Kong<sup>3</sup> · Qiang Wang<sup>1</sup> · Jon-Chao Hong<sup>4</sup>

Accepted: 21 October 2020 / Published online: 4 November 2020  
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## Abstract

Game-based learning supported by mobile intelligence technology has promoted the renewal of teaching and learning models. Herein, a model of Question-Observation-Doing-Explanation (QODE) based on smart phones was constructed and applied to science learning during school disruption in COVID-19 pandemic. In this study, from the theoretical perspective of cognitive-affective theory of learning with media, Bandura’s motivation theory and community of inquiry model, self-report measure was used to verify the effect of students’ scientific self-efficacy and cognitive anxiety on science engagement. A total of 357 valid questionnaires were used for structural equation model research. The results indicated that two types of scientific self-efficacy, as indicated by scientific learning ability and scientific learning behavior, were negatively associated with cognitive anxiety. In addition, cognitive anxiety was also negatively correlated to four types of science engagement, as indicated by cognitive engagement, emotional engagement, behavioral engagement, and social engagement through smart-phone interactions. These findings provide further evidence for game-based learning promoted by smart phones, contributing to a deeper understanding of the associations between scientific self-efficacy, cognitive anxiety, and science engagement. This study points out that the QODE model is suitable for implementing smart mobile devices to students’ science learning.

**Keywords** Distance education · Online learning · Mobile learning theory · Learning strategy · Science learning · Game-based learning

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✉ Qiang Wang  
qwchem@gmail.com  
Xiantong Yang  
xtyang93@foxmail.com  
Mengmeng Zhang  
1346988522@qq.com  
Lingqiang Kong  
KLq9598@163.com  
Jon-Chao Hong  
tcdahong@gmail.com

- <sup>1</sup> Research Center for Youth Science Popularization, College of Elementary Education, Capital Normal University, 105, West 3rd Ring North Road, Beijing, China
- <sup>2</sup> Department of Education, Beijing Normal University, 19, Xijiekou Street, Beijing, China
- <sup>3</sup> Shandong Feicheng Teaching Research Center, 4, Wenhua Road, Feicheng, Shandong, China
- <sup>4</sup> Department of Industrial Education, National Taiwan Normal University, 162, Heping East Road Section 1, Taipei, Taiwan

## Introduction

Affected by the new coronavirus, many countries have required schools to suspend classes in order to stop the spread of the virus, which poses a significant challenge for the normal schooling of 370 million students around the world (UNESCO 2020). It is noteworthy that the long-term isolation has created multiple difficulties for the students in online learning. Among them, the students have acquired serious stress responses because of the unknown serious infectious diseases (Samantha Kelly et al. 2018; Seyle 1956). In particular, COVID-19 seriously threatens the health of students and leads to anxiety and depression, which may affect learning engagement of students isolated at home (Li et al. 2020; Selcuk and Sukriye 2020). These negative emotions such as anxiety may influence the students’ memory and academic progress (Kizilbash 2002; Yeh 2007). Engagement and interaction between teachers and students during online learning are critical for students to construct an understanding of new knowledge (Zhu 2006). However, distance

learning leads to poor interaction effect and low learning engagement during epidemic (Garrison et al. 2001; Kanuka and Anderson 1998). All the above issues need to be mitigated urgently to enhance students' learning engagement.

According to the Community of Inquiry (CoI) model (Garrison et al. 1999; Remesal and Friesen 2014), learning takes place in the community through the interaction of cognitive presence, social presence, and teaching presence. First, learning participants construct meaning through continuous critical reflection and dialog in the inquiry learning community (Garrison 2011). Second, learners project themselves to CoI, using media to show real selves in social and emotional aspects (Garrison et al. 1999). Third, teaching presence promotes and guides learners' cognition and social process, helping learners achieve the learning effect of personal meaning and educational value (Garrison et al. 2001). Many studies have found that the CoI model can improve the interaction of members by creating an open inquiry learning atmosphere and strengthen community cohesion (Amanda et al. 2016; Selcan and Zahide 2018).

It has also been found that the inquiry project supported by technology can link the antecedents and consequences of students' behavior, feeling, and thinking mode so as to improve students' learning engagement (Mcconney et al. 2014; Jrvet et al. 2008). However, Pedaste et al. (2015) proposed that the validity of inquiry learning models would vary depending on the different educational context. Previous research models were all based on specific learning background, such as the 5E learning model proposed by Bybee et al. (2006), POE inquiry learning model proposed by Hong et al. (2014), and the five-step inquiry cycle proposed by White and Frederiksen (1998). However, the value of *Doing* of inquiry is not reflected in the previous model. Learning-by-doing has been emphasized as one of the important concepts of educational constructivism over a period of time (Taylor et al. 2004). Learning-by-doing environments have promoted participants' physical, social, and cognitive engagement in project (Edelson 1999; Gardner 2011; Papert 1980). Thus, in this study, we develop the Question-Observation-Doing-Explanation (QODE) inquiry model, which highlights the value of *Doing* in the process of problem-based inquiry. Finally, due to the domain specificity of learning engagement (Martin 2008), this study aims to verify the effect of QODE model during students' science learning engagement in combination with the background of science subjects. Meanwhile, the purpose of this study is to explore how cognitive anxiety and scientific self-efficacy affect students' learning engagement in the context of the epidemic.

## Theoretical Background

Learning engagement is a positive, substantial, stable, and lasting mental state related to learning (Schaufeli et al. 2002). Learning engagement is not only an important predictor of academic achievement, but also an effective observation index to measure learning quality and predict the development and growth of students (Christenson et al. 2012; Liu et al. 2017; Zhen et al. 2016). Although researchers have confirmed that learning engagement is domain specific (Martin 2008), studies have been sporadic on learning engagement in the context of science, so it is necessary to examine the factors that affect students' learning engagement in the epidemic situation.

Based on Bandura's motivation theory (Bandura and Schunk 1981; Bandura 1993), cognitive-affective theory of learning with media (CATLM) (Moreno 2006, 2009), and theory of CoI (Garrison 2011; Garrison and Akyol 2015), self-efficacy and cognitive anxiety are considered as the critical interactive psychology variable to explore science learning engagement.

## Learning Under the COVID-19 Pandemic

COVID-19 refers to pneumonia caused by 2019 novel coronavirus infection. As of July 1, 2020, it has infected more than 10 million people worldwide (WHO, 2020). As a serious infectious disease, COVID-19 can cause anxiety and other stress symptoms in the population. The long-term isolation at home and the suspension of production make the adverse impact of the epidemic even more serious. Among them, students across the globe move from in-person schools to online learning, which poses a serious challenge to the current online education.

According to the stress theory put forward by Selye (1950), stress is a state manifested through special syndrome, including all changes caused by non-specific biological system. Stressor refers to the stimuli that cause the stress response of the body (Selye 1952; Seyle 1956), including positive life events and negative life events. COVID-19 is a negative social stressor, which seriously threatens the health and safety of individuals. When stressors act on students, students always adopt physiological and psychological defense measures consciously or unconsciously in order to maintain their own psychological balance. Among them, anxiety is a process in which individuals respond appropriately to stress psychologically. Appropriate anxiety is conducive to enhancing the response speed and alertness of the brain, thus improving learning efficiency and satisfaction (Chen 2019; Hordacre et al. 2016), while excessive anxiety reduces students'

learning engagement and academic performance (Khng and Hui 2016; Ramirez et al. 2016; Scanlon et al. 2020; Shu-Yun Sophie 2013; Soltanlou et al. 2019). The impact of COVID-19 on students' home-based learning may be complex, so empirical research is needed to provide evidence to support students' home-based mobile learning.

Affected by the epidemic, mobile learning has developed rapidly in practice. The development of mobile communication technology makes the corresponding applications increasingly abundant. Applications based on mobile digital technologies, such as online video and games, have come out of the lab and into the classroom. Compared with other forms of learning, mobile learning has the advantages of convenience of learning environment, personalized teaching, interactive richness, contextual relevance, etc., and finally becomes a new form of digital distance education (Krishnapillai 2004). Mobile learning is based on informal learning theory and contextual learning theory. Among them, informal learning is a kind of implicit learning, which comes from direct interaction and suggestive information embedded in game learning (Gilliam et al. 2017). The convenient scene transformation of mobile learning makes learning no longer limited to formal places and formal courses, but gradually becomes a unique form of informal learning.

In addition, the contextual learning theory assumes that the individual instinctively searches for new information in the environment it is processing, making a meaningful relationship between the new information and its internal world (Mooij 2005). On this basis, contextual learning theory attaches importance to the analysis of learners' existing learning styles and aptitudes (Mooij 2007). In large class education, teachers often pay insufficient attention to learners' differences in learning motivation and interest, etc., while the personalized setting of mobile learning makes up for this deficiency.

Therefore, in the epidemic era, mobile learning provides a technical basis for the application of informal learning theory and contextual learning theory in teaching, while contextual learning theory provides a theoretical basis for the development of mobile learning. In addition, the epidemic situation and mobile learning theory promote each other, that is, the epidemic situation provides an environment and soil for improving the practice of mobile learning and promotes the prosperity of mobile learning. Similarly, mobile learning provides technical support and assistance for learning in the epidemic era.

### **Determinants of Cognitive Anxiety: Learning Self-efficacy**

Anxiety is a complex emotional state of tension, uneasiness, worry, and other unpleasant feelings caused by an

individual's coming and possible threat (Bauer and Julius 1965). Spielberger (1972) divided anxiety into trait anxiety and state anxiety. Martens et al. (1990) pointed out that state anxiety is domain-specific and contains multiple dimensions. On this basis, Weinberg and Gould (2003) classified its sub-components as cognitive and psychological anxiety. Hence, cognitive anxiety (CA) can be considered as a psychological component of state anxiety. It has been found (Hong et al. 2017) that CA is a key variable affecting self-confidence in the process of learning science through media. Furthermore, the binary coding theory holds the point that people have two cognitive systems, imagery system, and verbal system, which are independent but interrelated in function and structure (Paivio 1986). Based on this, Moreno further proposed CATLM (Moreno 2006, 2009) and believed that the dual-coding learning process was affected by emotion and motivation. In conclusion, it is reasonable to study CA as a sub-dimension of anxiety because this study aims to explore the impact of multimedia learning environment on students' learning science under the influence of epidemic situation based on CATLM.

According to Bandura's motivation theory (Bandura 1982), the learning self-efficacy can be defined as people's subjective judgment on whether they can succeed in learning. The learning behavior of human beings is influenced by the result factors and antecedent factors of behavior, where the former is the expectation of learning results, and the latter is the expectation of learning efficiency (Bandura 1989). When people are convinced that they are capable of learning science, they will have a high sense of self-efficacy to participate in learning activities (Britner and Pajares 2006). In combination with previous arguments (Gibson and Dembo 1984; Kairong et al. 1999), science self-efficacy can be divided into two types: self-efficacy of science learning ability (SSLA) and self-efficacy of science learning behavior (SSLB). SSLA refers to an individual's judgment and confidence on whether he has the learning ability to successfully complete his studies, obtain good grades, and avoid academic failure. SSLB refers to the individual's judgment and confidence on whether he can adopt certain learning methods to achieve the learning goal.

Current research has found that emotion rise is related to the formation of self-efficacy, high emotional arousal, and tense physiological state and can hinder behavior operation and reduce individual's expectation of success (Brígido et al. 2013; Holstermann et al. 2009). Specifically, people with a high level of anxiety tend to underestimate their ability. When individuals are in a state of excessive anxiety, anxiety will interact with fear to generate a vicious circle, which will eventually strengthen the sense of incompetence (Liu et al. 2018; Valentiner et al. 1996). At present, there are many studies on self-efficacy and general anxiety, but there is still a lack of research on the effect of scientific learning

self-efficacy on CA. In order to explore the influence of COVID-19 on students' self-efficacy in science learning, this study attempts to explore the relationship between self-efficacy in science learning and CA based on the research of general self-efficacy in Bandura's motivation theory. Hence, the following assumptions are proposed:

- H1. SSLA is negatively correlated with CA.
- H2. SSLB is negatively correlated with CA.

### **Determinants of Science Learning Engagement: Cognitive Anxiety**

As an important indicator to measure students' learning performance, learning engagement has been widely concerned by researchers in recent years (Johnson and Sinatra 2013; Skinner et al. 2009; Zhen et al. 2017). Learning engagement mainly refers to the social extent, behavior intensity, emotional quality, and the use of cognitive strategies of students involved in learning activities. It is generally divided into four dimensions: cognitive engagement, emotional engagement, behavior engagement, and social engagement (Finn and Zimmer 2012; Fredricks et al. 2004; Fredricks et al. 2016; Lam et al. 1999; Rimm-kaufman et al. 2014). It has been found that learning engagement exhibits certain domain specificity, and the same learners' learning engagement of different subjects has diversities (Martin 2008). At present, most of the investigations focus on the study of general learning engagement, but few studies of learning engagement concern scientific context. Science learning plays an important role in the development of students' logical thinking, spatial cognition, and other abilities (Floyd et al. 1992; Lynn 2000; Lynn et al. 2011). Therefore, to study the influencing factors and mechanism of science learning engagement in the context of epidemic situation is helpful to promote students' scientific learning better.

According to the CATLM (Moreno 2006, 2009), learners often need to invest and pay cognitive efforts in order to complete the learning task in the science learning supported by multimedia environment. Current research finds that negative emotions, such as online social anxiety, can decrease cognitive and behavioral engagement (Hwang et al. 2020). From the perspective of cognitive engagement, the theory of social psychology holds that positive emotions lead to heuristic processing strategies, while negative emotions lead to more systematic and analytical processing, making individuals pay more attention to the details of the environment (Bless 2000). Research on anxiety disorders has shown that negative emotions, such as CA, have negative effects on metacognition and fine processing strategies (Bridie and Sam 2008; Irak and Tosun 2008).

The effect of CA on behavioral engagement is controversial. According to the control-processing model, positive emotions can make the individual content with the status

quo and give up the goal they are pursuing; on the contrary, negative emotions, such as CA, can make an individual think that they have not made enough progress in the goal task, thus leading to the extension and enhancement of learning investment (Carver and Scheier 1990). Considering the influence of emotion on learning behavior, Pekrun et al. (2002) found that negative high arousal emotions such as anxiety were related to a low level of effort, indicating that anxiety may reduce learners' learning engagement. Branko (2001) also found that the stressful events that college students experience will affect their learning burnout. However, the above statements all aim at general learning engagement and lack of comparison from the comprehensive engagement, emotional engagement, behavior engagement, and social engagement.

The current research mainly focuses on the relationship between anxiety and cognitive, behavioral learning engagement, while the relationship between CA and scientific learning emotion, social engagement is relatively lacking. However, according to the CoI model, the emotional atmosphere between social groups and members of learning communities is the key variable that affects learners' learning engagement (Akyol and Garrison 2011). Garrison et al. (1999) pointed that CoI is able to use the atmosphere of social media to show real self in social and emotional aspects, and this kind of community atmosphere is one of the reasons why learners are attracted to it. Therefore, this research will further inquire about the CA and scientific cognitive engagement (SCE), scientific emotional engagement (SEE), scientific behavioral engagement (SBE), and scientific social engagement (SSE), and further propose the following assumptions.

- H3. CA is negatively correlated with SCE.
- H4. CA is negatively correlated with SEE.
- H5. CA is negatively correlated with SBE.
- H6. CA is negatively correlated with SSE.

### **Research Model**

According to the CATLM (Critchler and Ferguson 2011; Moreno 2006; Satpute et al. 2013), motivation theory (Bandura 1989), and CoI model (Garrison 2011), the present study proposes research hypotheses that indicate that SSLA and SSLB play an antecedent role in predicting that CA would lead to SCE, SEE, SBE, and SSE using smart phone and the QODE model in COVID-19 pandemic. Consistent with this research proposition and the previous review, the present study holds that self-efficacy of science learning will correlate with CA. In addition, CA will be associated with these sub-constructs of science engagement: SCE, SEE, SBE, and SSE. Hence, the following research model (Fig. 1) is proposed:

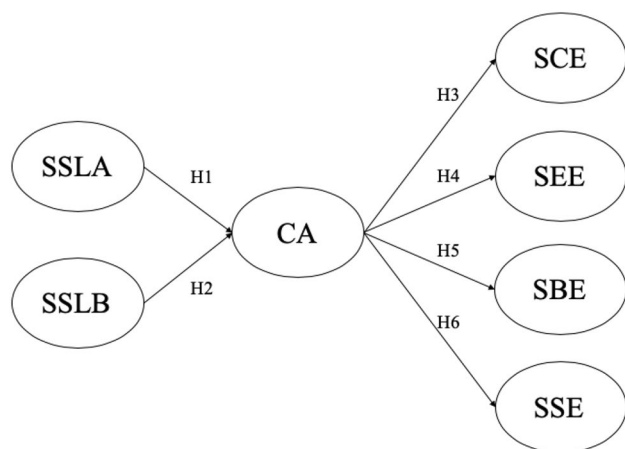


Fig. 1 Research model

## Research Design

*AU Learn Science*, a science-learning APP based on QODE inquiry learning model, was developed. Then, this APP was used for a quantitative cross-sectional study design. The game design of this APP and research procedure were presented as follows.

## Lesson Procedure

Pegg (2006) analyzed the existing scientific exploration models and classified them into POE, POCPE, and PCMGE. POE is the most concise scientific learning model, consisting of prediction, observation, and explanation. POCPE was an extension of POE, which complemented the data collection process. PCMGE was further modified on the basis of the previous two, adding two key steps of measurement and graph making.

According to theory of learning-by-doing (Lesgold 2001), doing with hands and brain is the tentacle of scientific exploration, which connects learners' thinking and objective world (Alvarez and Cerda 2003). However, the above three scientific learning models did not highlight the value of *Doing*. Therefore, based on the above model and learning by doing theory, the present study developed the QODE model, which includes four steps of question, observation, doing, and explanation. The first stage of question means to pose the misunderstanding regarding the current situation. Observation means that on the basis of a question, students use their senses to observe clues in the video directly according to a certain purpose, so as to obtain an understanding of the question. The critical stage of doing refers to the realization of the course task by students' hands-on practice. Explanation is the elaboration of the mechanism and reasons in the previous course tasks. In the distance learning, question firstly requires students to represent their doubts, observation



Fig. 2 Design of *AU Learn Science* APP

secondly requires students to observe phenomena and construct their own understanding of problems, doing thirdly requires students to turn their understanding in their minds into hands-on practice, and explanation enables students to deepen and broaden their understanding of problems. Next, *the role of the vaccine* in Fig. 2 was taken as an example to explain specifically how the QODE is implemented.

Based on the QODE model, the developed science-learning APP was used to set up a learning environment for learners. The design process of APP that explained the operation of QODE is presented in Fig. 2. Taking the *role of the vaccine* as an example: (1) Question: AU asks a question like “can a vaccine be effective for a lifetime?”. (2) Observation: Watch carefully how human cells fight against viruses. (3) Doing: operate T-lymphocyte and B-lymphocyte to eliminate the virus by using hands. (4) Explanation: combined with human immune mechanism, the principle and mechanism about the timeliness of vaccine were explained. Through the four-step QODE inquiry model, this APP supported students to learn science independently. WeChat, as a social software which also combined with *AU Learn Science* and work together, was used by teachers to assist discuss, which played a key role in building communities.

## Project Procedure

The samples in the study came from a research project named *Technology Supported Scientific Learning under Coronavirus Infection* launched in Shandong Province, China, from February to March 2020. The project aimed to implement the national call for *No Suspension of Classes* and provided science lesson for isolated students at home. Teachers and students who participated in the project completed two stages of learning and evaluation tasks after signing up voluntarily. In the first stage, the APP was downloaded into smart phones, and a total of six lessons (15 min per lesson) of 1 week were completed. In the second stage, in order to study the psychological state of students' learning under the

influence of the epidemic situation, a unified learning evaluation test was conducted online after the completion of the course learning. The process of project implementation is shown in Fig. 3.

The learning evaluation test adopts the questionnaire survey method, a non-intervention research method, which can be used to test students' learning psychological state. Due to its advantages of large-scale data collection and free from spatial restrictions, it has been widely used in educational research. Before the questionnaire was distributed, students and teachers voluntarily participated in the program and were informed that they could withdraw from the program at any time and that the data would be kept confidential. The study was carried out with the permission of local education authorities and the consent of local Ethics Committee. Questionnaires were collected through online questionnaire software and used for preliminary data collation and analysis.

## Participants

Throughout the study, 382 students from grade 3 to grade 5 participated in the course. Among them, 25 missing participants did not complete the final test due to equipment problems or illness, and the missing rate was 6.54% (less than 10%). According to the viewpoint of Hair et al. (2010), the number of missing participants is low, so it can be deleted in the subsequent analysis. Finally, 357 students completed the whole course and reported their achievements through questionnaires. Among them, 222 (62.2%) were in grade 3, 59 (16.5%) in grade 4, and 76 (21.3%) in grade 5. There were 182 boys (51%) and 175 girls (49%); the average age was 9.7 years ( $SD = 1.0$ ), and the age range was 8–12 years.

## Research Instruments

First of all, based on relevant questionnaires in previous studies, we revised the questionnaire in combination with science learning situations. All the questionnaires were scored according to a 5-point Likert-type scale. Secondly, the reliability and validity of the revised questionnaire were analyzed, which proved to be reasonable and effective.

## Research Questionnaire

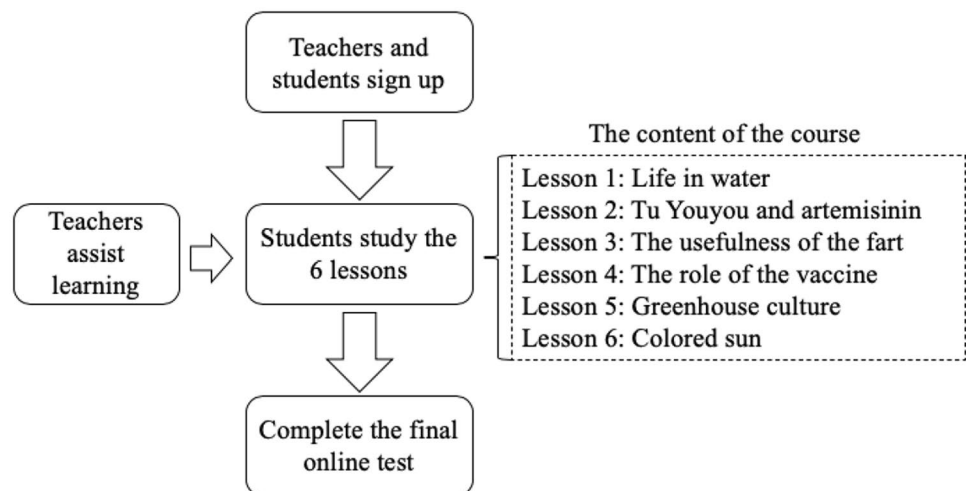
### Measurement of Scientific Self-efficacy

The revised self-efficacy scale was developed by Liang (2000) and used to measure Chinese students' scientific self-efficacy. The original scale was compiled by Pintrich and Groot (1990). In this study, it was revised in combination with scientific learning situations. The sample questions are as follows: *I believe I have the ability to get good grades in science studies*. The scale has a total of 16 items, which are divided into two parts: SSLA and SSLB. The students' sense of scientific self-efficacy increased with the increase of their scores.

### Measurement of CA

CA scale was used to measure students' CA level. The original scale was compiled by Burton (1998). This study revised it in combination with scientific learning situations. The sample question is *In the AU Learn Science game, I am worried that I would do wrong*. There are 8 items in the scale. The higher the score, the higher the level of CA.

**Fig. 3** Procedure of science learning project



## Measurement of Science Learning Engagement

In this study, the revised science learning engagement scale was used to evaluate the degree of students' engagement in scientific learning. The original scale was compiled by Wang et al. (2016). In this study, the scientific context was selected to revise the scale, and four dimensions of cognitive engagement, emotional engagement, behavioral engagement, and social engagement were selected. The revised scale has 31 items in total. For example, *I will do my science assignments carefully and make sure I do them correctly*. The higher the score is, the stronger the individual's science learning engagement is.

## Reliability and Validity Analyses

In the original questionnaire, there were eight items for SSLA, eight items for SSLB, eight items for CA, eight items for SCE, eight items for SEE, eight items for SBE, and seven items for the SCE dimension. According to confirmatory factor analysis, items with an indicator loading below 0.7 were deleted (Chin 1998). After cancelling the unreasonable items, revised questionnaire contained eight items for SSLA, eight items for SSLB, eight items for CA, seven items for SCE, eight items for SEE, seven items for SBE, and seven items for SCE. Next, the reliability and validity of the questionnaire were analyzed in the following steps.

First, the composite reliability (CR) was used to evaluate the internal consistency of the questionnaire (Fornell and Larcker 1981). As composite reliability values in this research ranged from 0.929 to 0.973, they all exceed the recommended threshold value of 0.7 (Hair et al. 2009; Nunnally 1978). Second, convergent validity in the present research was determined in order to ensure that the (1) the average variance extracted (AVE) values were higher than 0.5 (Fornell and Larcker 1981) and (2) the factor loadings of each items were greater than 0.5 and significant (Nunnally 1978). In the present study, AVE ranged from 0.653 to 0.819 and factor loadings ranged from 0.647 to 0.958, and all the conditions are satisfied to show that the convergent

validity is acceptable. Third, the independent *t* test was used to explain the discriminative degree of each item. According to Himmerlfarb (1993) and Cureton (1957), the discriminative indicators of the items could be assessed by testing the statistically significant difference between mean scores of people in the top 27% and mean scores of people in the bottom 27% of the subscale score distribution, and if the *t* value is greater than 3 ( $p < 0.001^{***}$ ), the discriminative power was significant (Green and Salkind 2004). The discriminative power was reasonable because the *t* value of all items was from 19.314 to 97.190 which are all larger than 3 ( $p < 0.001^{***}$ ).

Fourth, the Cronbach's  $\alpha$  was used to evaluate internal consistency reliability of the questionnaire. According to Nunnally (1978), the internal reliability is acceptable if the Cronbach's  $\alpha$  value is larger than 0.5. As shown in Table 1, the Cronbach's  $\alpha$  for the whole questionnaire in present research was from 0.805 to 0.968 (all larger than 0.5), indicating that the reliability of the questionnaire was acceptable. Fifth, Byrne (2001) suggested that the construct validity of the questionnaire would be examined by using confirmatory factor analysis. PLS also provides indicators such as SRMR and NFI. Because fitting indices such as SRMR and NFI are empirical standards (Browne et al. 2002), and the results of NFI and CFI were easily underestimated when the data are non-normal and small samples (Bentler and Bonett 1980), so the results in this study were acceptable (NFI = 0.734, SRMR = 0.101). Table 1 also shows that the means of each construct ranged from 1.712 to 4.457 and the *SD* was all below 0.942, thereby indicating that the construct validity of instruments was reasonable.

## Common Method Bias Test

Harman single factor test was carried out on the research data. According to the standard of characteristic root greater than 1, the results showed that 10 factors were extracted from unrotated factor analysis, and the variation of maximum factor variance interpretation was 33.19%, less than

**Table 1** Analyses of mean, *SD*, and Cronbach's  $\alpha$

Constructs	Number of items	Mean	<i>SD</i>	Cronbach's $\alpha$	NFI	SRMR
SSLA	8	4.206	0.886	0.961		
SSLB	8	4.248	0.902	0.968		
CA	8	1.712	0.942	0.952		
SCE	7	4.178	0.857	0.912		
SEE	8	4.323	0.868	0.939		
SBE	7	4.457	0.854	0.946		
SSE	7	4.215	0.844	0.912		
Total	53	3.906	0.597	0.805	0.734	0.101

**Table 2** The correlation matrix

	SSLA	SSLB	SCE	SEE	SBE	SSE	CA
SSLA	1						
SSLB	0.911**	1					
SCE	0.767**	0.813**	1				
SEE	0.793**	0.816**	0.853**	1			
SBE	0.777**	0.806**	0.830**	0.909**	1		
SSE	0.807**	0.843**	0.826**	0.852**	0.860**	1	
CA	-0.605**	-0.618**	-0.726**	-0.713**	-0.745**	-0.714**	1

the critical standard of 40% (Zhou and Long 2004), so there was no serious common method bias.

**Research Results**

PLS-SEM method has unique advantages in analyzing small sample sizes and non-normal data, and it can also be used in exploring research objectives and ensuring conversion (Hair et al. 2012; Ringle et al. 2012). Therefore, PLS-SEM method was used in this study. The software of SPSS 20.0 and Smart-PLS 2.0 was used to analyze the collected data. First, we used the Pearson’s correlation coefficient to estimate the degree of linear correlation among SSLA, SSLB, CA, SCE, SEE, SBE, and SSE. Second, the method of bootstrapping was used to estimate the sampling distribution and path coefficients, so that the measurements and structural models were examined. Finally,  $R^2$  was used to measure the explanatory power of the model.

**Correlation Analyses**

The results of Pearson’s correlation analyses are shown in Table 2. In the correlation matrix, after control of variables of gender and age, there were significant correlations among SSLA, SSLB, CA, SCE, SEE, SBE, and SSE. There was a significant positive correlation among SSLA, SSLB, SCE, SEE, SBE, and SSE, while CA was negatively correlated with other constructs. The correlative degree between SSLA and SSLB was the largest ( $r = 0.911$ ); however, the correlative degree between SSLA and CA was the lowest ( $r = -0.605$ ). All the coefficients were large, indicating that all the dimensions were highly relevant.

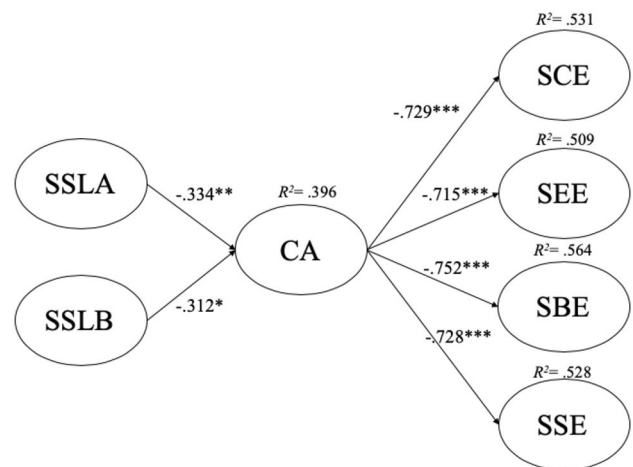
\*\*  $p < 0.01$

**Structural Model Analysis**

After analyzing the correlation among the variables and reliability and validity of the model, the explanatory and predictive power of the model was estimated. Table 3 and Fig. 4 show the supported results of the hypothesis. First, CA had a direct significant negative correlation with SCE, SEE, SBE, and SSE ( $\beta = -0.729, t = 17.058^{***}$ ;

**Table 3** Path coefficient  $\beta$ ,  $t$ -statistic,  $R^2$  of the PLS measurement model

Path	Path coefficient $\beta$	$t$ -statistic	Constructs	$R^2$
CA → SCE	-0.729	17.058***		
CA → SEE	-0.715	16.702***	CA	0.396
CA → SBE	-0.752	20.108***	SCE	0.531
CA → SSE	-0.728	17.282***	SEE	0.509
SSLA → CA	-0.334	2.652**	SBE	0.564
SSLB → CA	-0.312	2.429*	SSE	0.528



**Fig. 4** Verification of the research model

$\beta = -0.715, t = 16.702^{***}$ ;  $\beta = -0.752, t = 20.108^{***}$ ;  $\beta = -0.728, t = 17.282^{***}$ ). Furthermore, SSLA and SSLB had direct significant negative correlations with CA ( $\beta = -0.334, t = 2.652^{**}$ ;  $\beta = -0.312, t = 2.429^*$ ). In addition, according to the results of  $R^2$ , the explained variance of the SSLA and SSLB on CA was 39.6%, and the explained variance of CA on SCE, SEE, SBE, and SSE was 53.1%, 50.9%, 56.4%, and 52.8%, respectively. In conclusion, it could be determined that the independent variables had great reliability in the prediction and interpretation of dependent variables.

\*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$



## Discussion

In the present study, a QODE model was designed in the APP called *AU Learn Science* for elementary school students to learn science during COVID-19 pandemic. The APP integrated the QODE model, provided an opportunity for students to enhance learning engagement, and revealed the effects of scientific self-efficacy and CA on science engagement.

The results supported by the data were consistent with the initial research hypotheses, indicating that the theoretical hypotheses including H1, H2, H3, H4, H5, and H6 were all verified. From the view of Bandura's motivation theory (Bandura 1989), self-efficacy refers to an individual's subjective perception or belief in the ability to effectively control themselves that can result in long-lasting engagement for a certain learning topic. In the present study, the QODE model was designed by applying a science learning APP, which was expected to have a motivational impact on science learning engagement in the cognitive, emotional, behavioral, and social dimensions. Following the CATLM, positive or negative emotion factors play an intermediary role in the learning process by increasing or decreasing cognitive engagement (Moreno 2006, 2009). CA, as a cognitive component of anxiety (Ingram and Kendall 1987), weakens the role of self-efficacy and learning engagement.

In examining H1 and H2 hypotheses, the results of this research indicated that SSLA and SSLB were negatively correlated to CA after fixing the demographic variables. The result is supported by Singh, Bhadauria, Jain and Gurung (2013), who pointed out that increasing the level of anxiety would decrease the level of self-efficacy in learning with media. Li et al. (2020) pointed out that COVID-19 pandemic led to a sharp rise in the prevalence of anxiety in China. As the source and mechanism of COVID-19 have remained unclear, it aggravates one's CA in the epidemic situation, which will affect students' distance learning efficacy. From a cognitive-affective perspective, self-efficacy belongs to self-concept, which is related to CA as a part of state anxiety (Morony et al. 2013). Affected by the epidemic situation, on the one hand, students' anxiety level increases, which will damage the normal sense of scientific learning efficacy; on the other hand, the enhancement of scientific learning efficacy may help to reduce students' CA (Hong et al. 2017). This result is consistent with the assertion of Morris et al. (1981) and Tanaka et al. (2006), who advocated that anxiety is a tensional situation variables or transient experience of worry. Therefore, appropriate teaching and psychological guidance should be provided to improve students' self-efficacy, so as to reduce students' CA.

In examining hypotheses of H3, H4, H5, and H6, the results of this research indicated that CA was negatively

correlated to four types of learning engagement, including SCE, SEE, SBE, and SSE. This is consistent with those from previous studies (Pekrun et al. 2002). First of all, from the perspective of cognitive engagement, negative emotions will make individuals pay more attention to their surroundings and lose their attention to cognitive goals (Pintrich 2003). The negative emotions such as anxiety caused by the epidemic may damage the mediating effect of cognitive engagement on learning engagement (Shu-Yun Sophie 2013). Second, from the perspective of social engagement, the theory of CoI points that only through the interaction of cognitive presence, social presence, and teaching presence, learning could occur within the community (Shea and Bidjerano 2009). Social existence creates a purposeful online inquiry learning environment, in which learners' thoughts and ideas can be connected with each other (Shea and Bidjerano 2009). However, CA weakens the beneficial connection between social communication and learning engagement (Brom et al. 2014), consistent with the argument by Scanlon et al. (2020).

Third, from the perspective of emotional engagement, the epidemic removes the function of campus as a community, and emotional engagement becomes an isolated part ignored by educators in distance learning. Social presence includes three categories: emotional expression, open communication, and group cohesion, which emphasize the role of social factors in learning engagement. Among them, emotional expression attaches importance to students' emotional response and interactive response (Rourke et al. 2007). Therefore, CA also weakens the role of emotional engagement response and interactive response in emotional expression. Fourth, from the perspective of behavioral engagement, the research found that when students used APP for distance learning, CoI could promote their behavioral engagement and motivation structure (Shea and Bidjerano 2010), suggesting that CA played a negative role. To sum up, our study built a learning community for students to communicate with each other through the combination of *AU Learn Science* APP and social media called WeChat. At the same time, teachers are also able to guide students through WeChat and other social media, jointly played the role of online learning community in promoting learning engagement (Shea and Bidjerano 2009).

## Conclusion

Firstly, integrating the CATLM, Bandura's motivation theory, and CoI theory, learning engagement is positively affected by students' self-efficacy and negatively affected by students' CA. The present research confirmed that self-efficacy was a strong and direct determinant of student's learning engagement to practice the QODE application. It further

proved that student's learning engagement using distance learning derived a mixture of self-efficacy from CA via CoI.

Second, the above results show that science learning self-efficacy provides a feasible way to improve the science learning engagement, especially in distance learning in the post-epidemic era. Science learning self-efficacy, as a self-evaluation, provides a belief of confidence and competence in learning science. This belief strongly underlies the predictors of subsequent engagement in game-based science learning. Furthermore, the negative impact of CA is considered to deal with the anxiety caused by the epidemic. In the model of the present research, the negative effect of CA will reduce the engagement in science learning, including four aspects of SCE, SEE, SBE, and SSE. It is valuable that SSLA and SSLB, as the pre-variables of CA, can reduce cognitive anxiety by improving the science learning self-efficacy, and thus improve the engagement in science learning. Thus, the findings from these results provide an important contribution to game-based learning in the context of the epidemic.

## Contributions of Theory and Practice

To sum up, our research suggests two contributions both in theory and practice. From the perspective of theory, structural equation modeling is helpful to allow us to predict experimental outcomes. First, it is found that learning engagement of using intelligent devices comes from the self-efficacy in the process of distance learning. Second, the study discovers an in-depth relationship between science learning engagement comprised by SCE, SEE, SBE, and SSE and self-efficacy comprised by SSLA and SSLB, whereas prior research is limited to general dimensions of variables. Third, a more intensive understanding of CA in the long-distance online environment is enhanced. Fourth, the inquiry model of QODE, as a promising distance learning method, is constructed based on the prior learning theory, which offers crucial theoretical guidance during the COVID-19 epidemic. From the view of practice, the *AU Learn Science* APP is developed to promote and support students' science learning during COVID-19 epidemic. Using the QODE to integrate the CoI, students' science engagement can be cultivated. All these contributions are expected to set an effective example for other countries that are fighting against COVID-19.

## Future Study

Although some research findings and achievements have been made in this study, deficiencies remain. First, this study is a cross-sectional study, without a control group and an experimental group of comparative study. Thus, we are unable to obtain a strict sense of causality. Second,

using the method of self-report questionnaire data collection, there is a certain error in the subjectivity of the answer. However, by using the method of structural equation modeling, it also provides a reliable support for the research hypothesis and can have an enlightenment on the similar research on distance learning in the follow-up research.

In future research, experimental design can be used to further determine the causal relationship and internal mechanism between variables and to explore the change of students' learning with the development of the epidemic situation through tracking research. Furthermore, in order to help overcome the adverse effects of the epidemic on students, new ways of study need to be developed to assess the science learning engagement of distance learning from the perspective of psychological flexibility. A recent study of the effect of mental resilience on learning engagement (Yin et al. 2016) suggests that a mental resilience in response to stress status can be further used to examine the moderating effect between anxiety and engagement. In addition, regarding the educational diversity in the different geographic regions in China (Yang et al. 2019), it is worth carrying out follow-up work to verify the effect of APP in different cultural backgrounds. Therefore, in the post-epidemic era, improving mental resilience will help students from different regions cope with the anxiety brought by negative life events and facilitate the students' learning engagement to move forward in a positive direction.

## Disclaimer

We would like to submit the manuscript which we wish to be considered for publication in *Journal of Science Education and Technology*. No conflict of interest exists in the submission of this manuscript, and manuscript is approved by all authors for publication. The data in the article is open and transparent. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

**Author Contributions** Conceptualization: Xiantong Yang. Methodology: Xiantong Yang, Mengmeng Zhang. Formal analysis and investigation: Xiantong Yang, Mengmeng Zhang. Writing—original draft preparation: Xiantong Yang. Writing—review and editing: Qiang Wang, Jon-Chao Hong. Resources: Lingqiang Kong. Supervision: Qiang Wang, Jon-Chao Hong. I hope this paper is suitable for *Journal of Science Education and Technology*.

**Data Availability** The data in the article is open and transparent.

## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Ethical and Consent Statements** All human trials meet the ethical standards of the Chinese Association for Ethical Research (CAES). The informed consent of all participants participating in the study is obtained in accordance with CAES regulations.

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