Comparing the perception of emergency remote teaching experience between physics and nonphysics students

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A significant proportion of universities throughout the world switched from conventional face-to-face course delivery to emergency remote teaching (ERT) in response to the pervasive COVID-19 outbreak. A series of challenges are faced by both teachers and students as a result of the rapid and abrupt switch to ERT. Within the context of ERT, physics courses encounter certain challenges in contrast to certain liberal arts courses. In particular, this study sought to determine whether physics students and nonphysics students had diverse levels of flow experience and cognitive load when applying ERT during the global pandemic period. Furthermore, this study examined whether ERT for physics students varied depending on gender and educational level. Following the completion of their ERT courses at the end of both the Spring semester of 2020 and the Fall semester of 2022, a total of 1073 participants, including both physics majors and nonphysics majors, participated in our research. From the result, physics students had better performance in the flow experience encompassing its three constructs: enjoyment, engagement, and control. Physics students demonstrated a higher germane cognitive load and a lower extraneous cognitive load when compared to nonphysics students. Moreover, a considerably higher extraneous cognitive load was observed among male physics students than among their female counterparts during the ERT. Nonetheless, physics students at undergraduate and graduate levels did not significantly differ in their flow experiences or cognitive load. Overall, physics majors had a more positive perception of their ERT learning experience, and the impact of ERT on physics students was significantly less detrimental.

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I. INTRODUCTION

The COVID-19 epidemic that was pervasive worldwide in 2020 caused a significant shift in how students learned. Over 1.7 billion pupils were affected by the suspension of classes worldwide, according to a report from the United Nations Educational, Scientific, and Cultural Organization (UNESCO) [1]. It has become imperative for institutions to switch to fully online delivery because students are not allowed to participate in face-to-face classes in schools and universities [1,2]. The term "emergency remote teaching" (ERT), coined by Hodges *et al.* [3], describes this modern method of teaching and learning, suggesting that "a temporary shift of instructional delivery to an alternate delivery mode due to crisis circumstances." Presently, most schools and universities have resumed conventional face-to-face teaching across the globe. University still faces the possibility of switching from offline on-campus classes to emergency remote teaching whenever necessary.

With the rapid advancement in computer technology and the corresponding rise in Internet usage over the past ten years, online learning has become increasingly prominent at many universities. In the context of education, numerous research studies have been conducted on online learning [3,4]. Nevertheless, e-learning and ERT have diverse definitions, objectives, design methodologies, and means of instruction delivery [4]. Online learning utilizes an effectively devised curriculum to successfully combine synchronous, asynchronous, and autonomous learning activities [5]. Predominantly, it offers a meticulously crafted educational atmosphere [6] that fosters instructional adaptability with the prospect of offering students increased opportunities for learning [7]. On the contrary, ERT denotes a temporary switch in the mode of instruction when a crisis scenario arises, offering "a reliable, temporary, rapid, and lasting access" to instruction [8,9]. Teachers and students have encountered a variety of issues as a result of the

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sudden and abrupt transition to ERT [10–12]. Moreover, teachers are constrained by factors such as the absence of adequate teaching aids, resources, and time, which eventually impede them from rigorously designing and preparing relevant online activities and instructional materials for ERT [13]. The effectiveness of the instructional delivery method and the performance of the students and teachers in ERT have been the subject of research on ERT during the global pandemic. The impacts of ERT have been studied including many aspects, such as students' habits [14], well-being [15–17], integration [18], satisfaction with teaching [19], and academic performance [20–22]. However, research on epistemological impacts has not received enough attention. A few studies have investigated the changes in students' attitudes toward physics during the pandemic [23–25]. Furthermore, studies have observed that a variety of factors, including student attention levels [26], attitudes toward technology [27], and successful curriculum design [28], positively affect the outcomes of online learning. A significant proportion of studies have demonstrated that the transition to ERT has adversely affected pupils' mental health in certain situations [29] and produced pervasive negative reactions in them [30]. Therefore, it is necessary to pay attention to the university students' perception and experience in the ERT. The cognitive load and flow experiences of students are thought to be essential performance indicators of their learning process and their perceptions of learning. It is worth studying and exploring how switching to ERT affects students' flow experiences and cognitive load.

In addition, the world is changing and developing very fast. The pandemic has provided us a chance to learn how the teaching process responds to similar emergent changes. In the future, ERT may become more widespread [31]. It is necessary to pay attention to ERT, which is a remedial teaching method to cope with urgent changes.

II. LITERATURE REVIEW

A. Flow experience

According to Csikszentmihalyi's flow theory, people were considered to be in their optimum state and focused when they were engaged in a particular activity [32]. The concept of the optimal flow experience involves total immersion, the illusion of time passing fleetingly, and a sense of elation [33,34]. Well-defined goals, feedback, challenge-skill balances, an integration of action and awareness, a sense of control, concentration, time dilation, loss of self-consciousness, and gratifying experiences are generally adjudged to be components of the flow experience, according to prior literature [33–37]. Certain scholars put forth clearer and more specific structures. For instance, Webster *et al.* [38] offered four categories for the flow experience: control, focus of attention, curiosity, and cognitive enjoyment. The three constructs of perceived enjoyment, perceived control, and concentration are used in Koufaris' [39] paradigm to measure flow experience. The elements of flow experience including enjoyment, engagement, and control were separated by Pearce *et al.* [40]. These factors, which could be quantified more precisely and succinctly, were suitable as flow status indicators. Furthermore, Csikszentmihalyi [32] noted that it is feasible to adequately display these elements during the moment students feel delighted, engaged, and self-controlled while experiencing an activity.

Flow theory has been extensively applied to teaching and learning [41,42], consumer behavior [43], games [44], designs of multimedia materials [45], human-computer interaction [46,47], information management systems, etc. [48]. Previous research has suggested that the flow experience can serve as an important indicator for exploring students' learning status in a game-based learning environment [49–51]. Furthermore, researchers pointed out that flow experience is an important issue that deserves attention in the field of education, which helps ensure that learners are engaged in the learning process [52]. Ibanez *et al.* [53] noted that cultivating the flow state of students is also one of the tasks of education.

Flow theory has now been introduced into the field of online learning [54], to study the impact of online learning modes on the learner experience. Some studies investigated learners' flow experience under different online instructional designs [55,56], instructional materials [57], and instructional technology [58,59]. For example, Zhao and Khan [56] explored students' flow experience with the continuous intention of using online English platforms. Some studies examined the relationship between flow experience and other factors in online learning, including academic achievement [60], self-efficacy [61], motivation [62,63], and learning interesting [64], and explored the interaction between these factors and flow experience on learning [60,65,66]. For instance, a study proposed a "prediction-observation-quiz-explanation" model to design a green energy generation online learning and explored the relationship between flow experience, cognitive load, self-efficiency, and the intention to continue online learning [67]. In this study, we adopted the flow experience model with three dimensions of enjoyment, engagement, and control proposed by Pearce *et al.* [40] to explore university students' flow experience in ERT. It suggested that people can effectively perceive enjoyment, engagement, and control when they are fully immersed in an activity. In pedagogical practice, enjoyment implies appreciation shown by a student experiencing a certain teaching process. Engagement refers that a student is engaged in and concentrating on the teaching activity. Control refers to students' sense of autonomous control over learning activities [35–37].

B. Cognitive load

Cognitive load theory (CLT) was first proposed by Sweller [68]. The core of cognitive load theory is working memory. Emphasis has been placed on the fact that human working memory is restricted in capacity as regards the amount of information it can process, and this memory capacity can be readily overwhelmed by diverse categories of load. It is pointed out that our working memory can only deal with a limited amount of information at once and the different categories of load that can fill memory capacity [69]. According to the theory, it partitioned the working memory demands of instructional settings into three load types, intrinsic cognitive load, extraneous cognitive load, and germane load. Intrinsic cognitive load (ICL) relates to the difficulty of learning materials and cannot be directly manipulated by instructional designers. Extraneous cognitive load (ECL) relates to inappropriately designed instructional materials and could be influenced by instructional designers, while germane cognitive load (GCL) relates to the working memory resources that learners dedicate to the information pertinent to learning [70]. It has been proposed that information under- or over-representation tends to bring about a significant cognitive load and interfere with learning. Information must be presented in a way that lessens superfluous cognitive load and enhances cognitive load that is pertinent to learning to effectively deliver instruction [71].

CLT is central to instructional design in online learning. It identified the cognitive processes that learners engage in during the learning process [72]. Consequently, it is crucial to examine the cognitive load of students during the teaching procedure. A significant number of academics have implemented CLT in educational research to examine topics such as how instructional information is presented, how student learning materials are devised, and how cognitive load affects instruction or student learning. For example, Lai *et al.* [73] developed an AR-based science learning system adopting CLT. Through subsequent experiments, they discovered that this technique considerably reduced students' sense of extraneous cognitive load. Chen *et al.* [74] proposed instructional design principles based on CLT to structure online learning platforms such as massive open online courses. Eitel *et al.*'s research [75] highlighted the correlation between self-management and both self-regulated learning and cognitive load. According to Altinpulluk *et al.* [76], breaking up an instructional video into multiple relevant aspects could lessen learners' cognitive load. Younas *et al.* [77] found that the shortcomings in online learning systems negatively impact learners' attitudes and intention to use and substandard interface design, in particular, might elevate the cognitive load that ultimately affects the learner's intention to use. Conrad *et al.* pointed out that [78] the effects of cognitive load on the perceived difficulty of online learning, and in turn, on online learning satisfaction.

C. Efforts and challenges in emergency remote teaching (ERT)

During the COVID-19 pandemic, courses at many universities have moved toward fully online delivery. The ERT could mitigate the losses suffered by students during the pandemic [21]. Based on the experience with online education and evolving technology, instructors and researchers in various countries have improved instructional strategies and course designs for ERT. Many districts offered remote learning plans, which might include formal curriculum, assignments, progress monitoring, and access to general educational resources. Additionally, ERT has implemented instructional strategies such as case studies, online lectures, instructor notes, miniprojects, remote seminars, and online forums [79]. French medical students were taught via video conferencing for certain theoretical and liberal arts courses [80]. Courses in art and design placed a strong emphasis on interactions between students and teachers [81]. The program offered a participatory platform and comprised diverse activities such as reading, comprehension, and video viewing. Furthermore, students were provided the opportunity to form groups during the online courses through the use of various technical tools such as Google Groups tools, Doodle, Twitter, WhatsApp, and Pinterest. Certain liberal arts courses had access to online lectures in Korea [82].

For science, technology, engineering, and mathematics (STEM) education, laboratory work and hands-on practices are essential components of STEM-related courses, such as physics courses. Students were frequently required to engage in more practical activities in these courses that emphasize applied skills [83]. Even though in-person instruction was impossible during the COVID-19 epidemic, various technical tools might be employed to set up a setting for students to carry out practical tasks. Physics courses were required as part of the public basic curriculum for many STEM-related degrees. Remote laboratories and simulation-based laboratories have been implemented in online physics courses. A few claimed that ERT had moved several face-to-face laboratory methods online [83,84]. Physics laboratories have employed a variety of methods to enhance online physics courses in higher education, including providing students with a personalized lab kit and a video presentation with real data to analyze [85–89]. Other strategies include setting up online simulation experiments and having students conduct a variety of physical experiments at home using inexpensive or readily available equipment [83]. Under the auspices of the Jožef Stefan Institute, students pursuing reactor physics could participate in remote exercises and conduct physics experiments from home through organized activities [90].

The rapid and unexpected shift to ERT has created many challenges for students. Evidence suggested that the measures adopted by schools may not have been as successful as anticipated. According to the students' perception, they assumed that face-to-face English education classes were less boring than those conducted online [91]. Furthermore, a significant, detrimental effect on student learning was anticipated as a result of the severe disturbance online [21,92]. Students' normal schedules and study habits were disrupted by the sudden shift in the course modality. Even when professors post their lesson plans online, evidence suggests that a considerable number of students lack access to these resources from home [21]. Moreover, there is an absence of time for teachers and students to interact face-to-face. According to the existing study, students perceived that there has been a considerable decrease in the amount of interaction in their classes, and they feel that this decrease has had a detrimental effect on their learning [93]. In addition, despite grade gains, students reported less confidence in their ability to learn, less knowledge gained, and less preparedness for the future during the ERT [94]. However, a study examined how student perceptions of experimental physics were affected by changes in course mode during the epidemic. The results revealed that students' overall E-CLASS scores were not lower in 2020 compared to 2019 [24]. It was evident that this reflected the extraordinary efforts of instructors in preparing the experimental course for the spring semester. Participants also felt that participating in virtual experimentation activities helped them improve their physics learning, including a better understanding of conceptual knowledge and a higher level of problem-solving skills [95]. Based on these, physics courses in the ERT, which were implemented in a different variety of ways as they were in certain theoretical or liberal arts courses, place a stronger emphasis on practical skill exercises. Different instructional strategies and teaching activities may bring different experiences for students.

III. PURPOSE AND RESEARCH QUESTION

Considering the efforts and obstacles, it is essential to examine how students fared while receiving ERT at the university. In the current study, the emphasis was on two critical aspects of students' perceptions of the ERT experience—flow experience and cognitive load—based on a thorough literature review. There are specific challenges for physics courses under ERT in comparison to some liberal arts courses. This study investigated whether there are differences in both flow experience and cognitive load in ERT between students who took physics courses and those who took liberal arts courses without taking any physics courses.

Additionally, it has always been comprehended that gender disparities in educational contexts are essential educational research topics [95,96]. Numerous studies have explored the impact of gender on a variety of online learning indicators, including learning outcomes [97], cognitive load [98], attitude [98], perceived quality of interaction [99], online learning behavioral patterns [96], and self-efficiency [99]. Previous research findings had contrasting outcomes about gender differences in online learning. A study found that females are more capable than males of learning online and have superior learning outcomes [97]. Hong *et al.* [96], meanwhile, observed that the gender of the participants affected how ineffectively they learned online, with girls having higher tendencies than boys to experience this ineffectiveness in online experimental courses. Yu [98] conducted a study on undergraduates to determine gender differences in cognitive loads, attitudes, and academic achievements in English language online learning. The study demonstrated that males have significantly less cognitive load when learning English through the mobile learning platform, and males assess the mobile learning platform more favorably than females do. Likewise, males improved their English proficiency better than females when using the mobile learning platform. Although males were statistically significantly more satisfied than females, females had statistically significantly higher self-efficiency in online English instruction [99]. In light of the contradictory findings, it is vital to investigate the gender variations in students' perceptions of the ERT experience in physics courses.

Moreover, diverse educational levels, including undergraduates and postgraduates, are included in the current round of ERT in higher education. Studies have explored how learners' educational backgrounds impact their capacity to learn online. Variable educational level groups exhibit dramatically varying levels of student readiness for live online instruction [100]. Undergraduate students rated online courses less positively than face-to-face courses regarding their ability to impart knowledge, stating that online learning was not the most effective instructional strategy [101]. Higher learning outcomes than undergraduates were achieved by postgraduates who preferred the online learning environment to the conventional classroom setting [102]. Graduates further expressed greater levels of self-efficacy and satisfaction with online training than freshmen, sophomores, and juniors. Resultantly, the current study also involved investigating whether educational levels (undergraduate and postgraduate) had an impact on flow experience and cognitive load in ERT of physics courses.

The following research questions are proposed based on the discussion above:

(1) Do students' flow experience and cognitive load during ERT vary between physics student and non-physics student groups?
(2) Does gender affect the flow experience and cognitive load of physics students during ERT?
(3) Do physics students' flow experience and cognitive load during ERT vary between undergraduate and postgraduate groups?

IV. METHODOLOGY

A. Design

Many universities in the People's Republic of China provided ERT for all classes during the COVID-19 pandemic during the Spring 2020 and Fall 2022 semesters. Courses were delivered synchronously using web conferencing tools (e.g., Tencent Meet and Zoom) and asynchronously using digital content. Students taking physics courses at this university were required to obtain both academic knowledge and practical abilities. To provide students with access to experimental settings, instructors absorbed virtual simulation technology for online physics experimental instruction delivery during ERT. Students would get virtual practice afforded in laboratory simulations. Furthermore, students were anticipated to complete the related experimental objectives, as well as engage in hands-on operation, data collection, analysis, and experimental report writing. The simulation lab has provided students with the chance to conduct basic online experiments both as a part of the theoretical course and its related lab.

In the current study, the research objects were divided into two groups to examine how physics students and nonphysics students perceived ERT differently. The physics students were those who pursue a degree in physics. As nonphysics students, the study enlisted the help of some liberal arts students majoring in areas other than physics, such as finance, psychology, Chinese language and literature, social management, and tourism management. They were not required to complete any physics courses and had no physics experiments online. The ex-post evaluation of ERT by students was focused on in this study. Students were required to evaluate their experiences with ERT following the completion of their courses using a survey of flow experience and cognitive load. Some were scheduled at the end of the spring semester of 2020 and others were at the end of the fall semester of 2022. Furthermore, another objective of this study was to determine whether distinct effects on ERT for physics students exist at different educational levels and across genders.

B. Instrument

A questionnaire was used to investigate students' flow experiences and cognitive load in ERT. The questionnaire consists of two parts, the flow experience scales and the cognitive load scales. The measures used in this study were primarily adapted from relevant prior studies and the content of this questionnaire had been modified to fit the ERT.

A flow experience scale was developed by Pearce *et al.* [40] and included three constructs which were enjoyment, engagement, and control. It was further improved by Chang *et al.* [50]. This version of the scale was adopted for use in the present study, in which the statements were slightly modified to make them suitable for ERT learning. There were 12 items on the scale, 4 items for each subscale. Each item was rated on a five-point Likert-type scale ranging from 1 "extremely disagree" to 5 "extremely agree" to report respondents' level of agreement with the items. The higher the scores were, the higher the flow experiences students would have.

The cognitive load scale was developed by Chang *et al.* [50] based on one cognitive load scale with five items initially proposed by Gerjets *et al.* [103] and a ten-item cognitive load instrument from Leppink *et al.* [104]. The scale consisted of 12 questions and included three subscales of intrinsic (4 items), extraneous (4 items), and germane (4 items) cognitive load. It is also a 5-point Likert-type scale with response options from 1 (extremely disagree) to 5 (extremely agree). The original wording was modified to align with the features of ERT in the present study.

The questionnaire was translated into Chinese by a professor and a teacher and it was further proofread by three teaching assistants for readability. The survey took between 10 and 15 min to finish. The English version of the questionnaire is presented in the Appendix.

C. Participant and procedures

The participants of this study were enrolled in a university in the southern part of the People's Republic of China. The participant sample included students who had taken ERT in the spring of 2020 from April 1 to July 15 and another group who had taken ERT in the fall of 2022 from October 24 to December 25. The questionnaire was distributed to obtain students' perspectives about their flow experiences and cognitive load in ERT. A total of 101 physics students participated in our research. Among them, there were 69 females and 32 males, 48 undergraduates, and 53 postgraduate students. The questionnaire was also administered to nonphysics students of liberal arts majors. There were 972 nonphysics students, 564 of whom were female and 408 were male. There were 719 undergraduates and 253 postgraduates. In total, there were 1073 participants, including 633 females and 440 males, 767 undergraduates, and 306 postgraduates.

The questionnaire was distributed to participants of different majors with the help of their school counselors through the network platform. Students completed the questionnaire about their flow experience and cognitive load after completing their courses at the end of the semester. All participants in the study voluntarily elected to participate in the questionnaire. It should be noted that no additional academic credits were granted to students for completing the questionnaire. The questionnaire duration was estimated to range between 10 and 15 min.

TABLE I. Descriptive statistics of students' flow experience and cognitive load scores.

	Participants		Physics students		Nonphysics students		Physics students				Physics students			
							Male		Female		Undergraduate		Postgraduate	
	($n = 1073$)		($n = 101$)		($n = 972$)		($n = 32$)		($n = 69$)		($n = 48$)		($n = 53$)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Flow experience	40.19	7.29	43.60	5.93	39.84	7.32	42.78	5.87	43.99	5.97	43.48	5.21	43.72	6.57
Flow-enjoyment	13.24	3.04	14.19	2.48	13.14	3.08	13.93	2.37	14.30	2.54	14.40	2.25	14.00	2.68
Flow-engagement	12.81	2.58	13.60	2.45	12.72	2.58	13.16	2.58	13.81	2.38	13.31	2.24	13.87	2.62
Flow-control	14.15	2.76	15.81	2.19	13.97	2.75	15.87	2.16	15.87	2.21	15.77	2.03	15.85	2.34
Intrinsic cognitive load	10.96	3.15	9.72	2.95	11.08	3.13	11.25	3.38	10.75	2.96	11.16	3.09	10.45	3.23
Extraneous cognitive load	10.47	3.37	9.13	2.92	10.61	3.38	10.16	2.71	8.65	2.90	8.90	2.73	9.34	3.09
Germane cognitive load	12.55	3.26	13.31	3.29	12.47	3.25	13.31	3.14	13.30	3.38	13.23	3.10	13.38	3.48

D. Data analysis

The following statistical techniques were adopted throughout the data analysis: The instrument's Cronbach's alpha was initially computed. The Cronbach alpha coefficient ranges from 0 to 1. A value greater than 0.7 is generally considered sufficient for the internal consistency of the test. The flow experience scale's Cronbach's alpha coefficient was 0.868, while the cognitive load scale's Cronbach's alpha coefficient was 0.882. Thus, it implied that the internal consistency and dependability of the two instruments were satisfactory. For the second step, the participants' scores were calculated to provide a descriptive analysis of the students' findings. Subsequently, the Mann-Whitney U tests were computed to compare how physics students and nonphysics students fared in terms of flow and cognitive load during ERT. The Mann-Whitney U tests were also utilized to determine whether variations exist both in physics students' flow experiences and in cognitive loads according to gender and educational level. The Mann-Whitney U test, which is one kind of nonparametric test, is used when the data do not meet the requirements of the independent samples t test. The purpose is to find out whether the data of the two samples are significantly different.

V. RESULT

Table I displays the mean scores and standard deviations of flow experience and cognitive load for all participants and each group of students labeled by the different variables, including majors, gender, and educational level. In total, there is the full mark of 60 points for the whole flow experience and 20 points for each construct. As for the cognitive load, the maximum score for each type of cognitive load on the scale is also 20 points. It is worth noting that the higher the intrinsic load and the external load, the more unfavorable for learning, and the higher the germane load could be more productive for learning. The overall mean score of flow experience for all participants was 40.19 ($SD = 7.29$). Students achieved an average score of 13.24 ($SD = 3.04$) on the enjoyment items, 12.81 ($SD = 2.58$) on the engagement items, and 14.15 ($SD = 2.76$) on the control items. For cognitive load, relative to the mean scores of intrinsic cognitive load ($M = 10.96$, $SD = 3.15$) and extraneous cognitive load ($M = 10.47$, $SD = 3.37$), the mean score of germane cognitive load ($M = 12.55$, $SD = 3.26U$) was higher. When it comes to different variables, physics students outperformed nonphysics students, female physics students outperformed male physics students, and physics postgraduates outperformed physics undergraduates, in both flow experience and cognitive load.

A. Physics students versus nonphysics students

1. Flow experience

Figure I shows the results of Mann-Whitney U tests for flow experience scores and cognitive load between the physics students and nonphysics students. For flow experiences in ERT, there was a significant difference ($U = 33757.500$, $Z = -5.177$, $p < 0.001$, Cohen's $d = 0.32$) between the two groups, as shown in Table II. According to Table I, the mean score for the physics students ($M = 43.60$, $SD = 5.93$) was significantly higher than that for the nonphysics students ($M = 39.84$, $SD = 7.32$). In other words, physics students reported significantly better flow experience than nonphysics students in ERT.

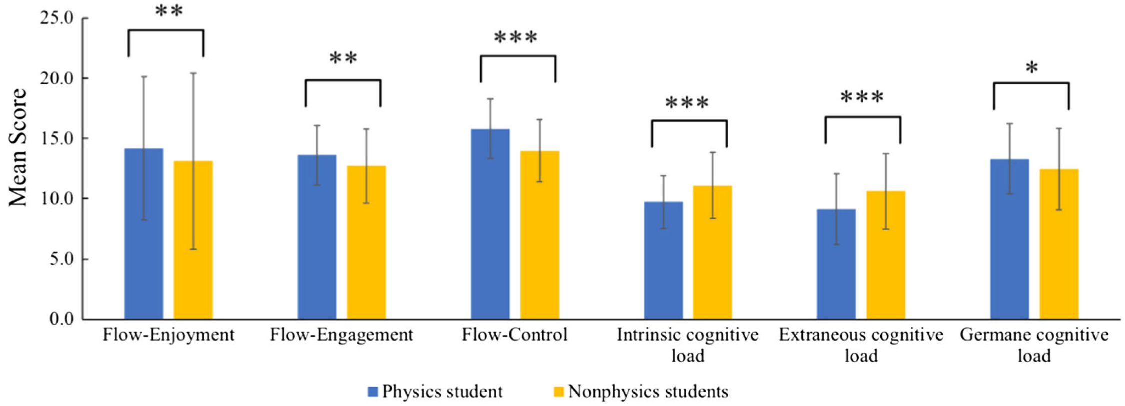

FIG. 1. Mean values of the scores of physics students and nonphysics students of questionnaires during ERT. Whiskers indicate standard deviation. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

From Table II, it is also shown that there were significant differences in enjoyment ($U = 39120.500$, $Z = -3.383$, $p < 0.01$, Cohen's $d = 0.206$), engagement ($U = 39164.500$, $Z = -3.378$, $p < 0.01$, Cohen's $d = 0.205$), and control ($U = 30060.500$, $Z = -6.463$, $p < 0.001$, Cohen's $d = 0.400$) between the physics students and nonphysics students. Among the three constructs of flow experiences, the difference between the scores of physics students and nonphysics students was the most significant in the control construct. Table I indicates that the nonphysics students ($M = 13.97$, $SD = 2.75$) rated control significantly lower than the physics students ($M = 15.81$, $SD = 2.19$). In general, Cohen's d is a small effect between 0.2 and 0.4, a moderate effect between 0.4 and 0.7, and a large effect above 0.7 [105]. According to the magnitude of the effect size, the difference of control between the physics students and nonphysics students reached a medium level (Cohen's $d = 0.400$).

2. Cognitive load

The differences in the scores of cognitive loads were analyzed between the physics students and nonphysics students to explore students' perceptions of their learning load in ERT. There were significant differences in intrinsic cognitive load ($U = 36254.500$, $Z = -4.367$, $p < 0.001$, Cohen's $d = 0.267$), extraneous cognitive load ($U = 37018.500$, $Z = -4.094$, $p < 0.001$, Cohen's $d = 0.251$), and germane cognitive load ($U = 42019.000$, $Z = -2.404$, $p < 0.05$, Cohen's $d = 0.146$) between the physics students and nonphysics students, as shown in Table III.

TABLE II. Results of Mann-Whitney U test on flow experience between physics students and nonphysics students. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

	Major			
	Physics students ($n = 101$) vs nonphysics students ($n = 972$)			
	U	Z	p	Cohen's d
Flow experience	33757.500	−5.177	0.000***	0.320
Flow-enjoyment	39120.500	−3.383	0.001**	0.206
Flow-engagement	39164.500	−3.378	0.001**	0.205
Flow-control	30060.500	−6.463	0.000***	0.400

TABLE III. Results of Mann-Whitney U test on cognitive load between physics students and nonphysics students. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

	Major			
	Physics students ($n = 101$) vs nonphysics students ($n = 972$)			
	U	Z	p	Cohen's d
Intrinsic cognitive load	36254.500	−4.367	0.000***	0.267
Extraneous cognitive load	37018.500	−4.094	0.000***	0.251
Germane cognitive load	42019.000	−2.404	0.016*	0.146

TABLE IV. Results of Mann-Whitney U test on flow experience (including three constructs) between male physics students and female physics students. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Gender				
Male ($n = 32$) vs female ($n = 69$)				
	U	Z	p	Cohen's d
Flow experience	967.000	−1.003	0.316	0.200
Flow-enjoyment	1017.000	−0.642	0.521	0.127
Flow-engagement	968.500	−0.998	0.318	0.198
Flow-control	1042.500	−0.453	0.650	0.089

The physics students reported statistically lower extraneous cognitive load than the nonphysics students, but a higher germane cognitive load ($M = 13.31$, $SD = 3.29$) than the nonphysics students ($M = 12.47$, $SD = 3.25$). That is, physics students in ERT had lower extraneous cognitive load and higher germane cognitive load than nonphysics students.

B. Gender

1. Flow experience

To study the gender difference and educational level difference in student flow experience and cognitive load, the participant sample of physics students was taken as the next analysis group. A Mann-Whitney U test was used to compare the difference in flow experience between different genders of physics students. As can be seen from Table IV, there was no significant statistical difference in flow experience scores according to the gender of physics students ($U = 967.000$, $Z = -1.003$, $p = 0.326$, Cohen's $d = 0.200$). That is, female and male students acquired similar scores in flow experience scales. Relative to the maximum score of flow experience on the scale (maximum score = 60), students' flow experiences with ERT were largely positive (see Table I). Furthermore, there were no significant gender differences in the three constructs of flow experiences.

2. Cognitive load

The gender differences in physics students' cognitive load are shown in Table V. A significant difference was found between female and male physics students in extraneous cognitive load ($U = 801.500$, $Z = -2.226$, $p < 0.005$, Cohen's $d = 0.450$). Compared to male physics students ($M = 10.16$, $SD = 2.71$), female physics students ($M = 8.65$, $SD = 2.90$) had a lower extraneous cognitive load in ERT (see Table I). However, no gender difference in intrinsic cognitive load and germane cognitive load was found in the sample of physics students.

TABLE V. Results of Mann-Whitney U test on cognitive load between male physics students and female physics students. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Gender				
Male ($n = 32$) vs female ($n = 69$)				
	U	Z	p	Cohen's d
Intrinsic cognitive load	1021.500	−0.609	0.543	0.120
Extraneous cognitive load	801.500	−2.226	0.026*	0.450
Germane cognitive load	1075.500	−0.210	0.834	0.041

C. Undergraduates versus postgraduates

1. Flow experience

Another aim of this research was to compare the differences in flow experience (including three constructs) between physics undergraduates and physics postgraduates. As shown in Table VI, it can be seen that no significant difference was found in the flow experience between physics undergraduates and physics postgraduates ($U = 1257.000$, $Z = -0.102$, $p = 0.919$, Cohen's $d = 0.020$). As for the three constructs, there were also no significant differences in enjoyment ($U = 1127.500$, $Z = -0.993$, $p = 0.321$, Cohen's $d = 0.196$), engagement ($U = 1136.500$, $Z = -0.930$, $p = 0.353$, Cohen's $d = 0.184$), and control ($U = 1246.000$, $Z = -0.179$, $p = 0.858$, Cohen's $d = 0.035$) between the two groups.

2. Cognitive load

The possible performance differences in cognitive load were explored between physics undergraduates and physics postgraduates. The results of the Mann-Whitney U test on physics students' cognitive load between the two groups are given in Table VII. No significant differences were found in intrinsic cognitive load ($U = 1264.000$,

TABLE VI. Results of Mann-Whitney U test on flow experience (including three constructs) between physics undergraduates and physics postgraduates. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Education level				
Undergraduate ($n = 48$) vs postgraduate ($n = 53$)				
	U	Z	p	Cohen's d
Flow experience	1257.000	−0.102	0.919	0.020
Flow-enjoyment	1127.500	−0.993	0.321	0.196
Flow-engagement	1136.500	−0.930	0.353	0.184
Flow-control	1246.000	−0.179	0.858	0.035

TABLE VII. Results of Mann-Whitney U test on cognitive load between physics undergraduates and physics postgraduates. Note that $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Education level				
Undergraduate ($n = 48$) vs postgraduate ($n = 53$)				
	U	Z	p	Cohen's d
Intrinsic cognitive load	1264.000	−0.055	0.956	0.011
Extraneous cognitive load	1121.500	−0.415	0.678	0.205
Germane cognitive load	1268.000	−0.027	0.978	0.005

$Z = -0.055$, $p = 0.956$, Cohen's $d = 0.0011$), extraneous cognitive load ($U = 1121.500$, $Z = -0.415$, $p = 0.678$, Cohen's $d = 0.205$), and germane cognitive load ($U = 1268.000$, $Z = -0.027$, $p = 0.978$, Cohen's $d = 0.005$) between physics undergraduates and physics postgraduates. Physics students' cognitive load in ERT was independent of educational level.

VI. DISCUSSION

The study concentrated on the ex-post evaluation of ERT by university students in 2020 and 2022. With a focus on flow experience and cognitive load, the objective was to explore how physics and nonphysics students perceived their ERT experiences. Moreover, the impacts of gender and educational level on the physics students' ERT flow experience and cognitive load were investigated.

A. The perception of ERT experience between physics and nonphysics students

Regarding the first research question, the findings of the study indicated that physics students and nonphysics students have diverse perspectives on ERT. Physics students had better performance in both flow experience and cognitive load. It was reflected by the higher score of flow experience, including the three constructs of flow experience. Moreover, the results also indicated that the self-rated cognitive load of the physics students was considerably dissimilar to those of nonphysics students. According to the cognitive load theory, the intrinsic load was primarily determined by the learning material instead of the instructional mode. It was obvious that the difference in intrinsic cognitive load existed between the physics students and nonphysics students. However, the present focus was on the difference in cognitive load between physics and nonphysics students due to the ERT mode, therefore, the extraneous cognitive load and the germane cognitive load were worth analyzing. Compared to nonphysics students, physics students experienced a lower extraneous cognitive load and a higher germane cognitive load. That is, physics students had a less irrelevant cognitive load, which is more conducive to their learning.

From our results, physics students believed that the mode of delivery in ERT had a less negative impact on their learning. Students majoring in physics had higher flow experience and lower cognitive load than those of liberal arts majors in ERT. This finding supported some previous studies on the differences between online and face-to-face teaching of science and liberal arts courses. Schoenfeld-Tacher *et al.* [106] found that students in online courses performed better than students in face-to-face courses in high-level science courses. Nevertheless, Johnson and Palmer [107] observed that face-to-face students had a higher sense of engagement and outperformed their online counterparts in a linguistics course. A qualitative analysis that investigated students' different feelings on the content-based versus skills-based course types and online versus face-to-face classroom styles identified that most students regarded content-based online courses as duller due to the lecture-style structure [91]. Furthermore, Helms [108] found that online undergraduate students performed worse than their face-to-face peers in a psychology course. The reason related to this difference might be explained by the fact that physics students were more proficient in using computers or other electronic devices when conducting online experiments during ERT. A similar study conducted by Hillier [109] examined the performance of undergraduates in different majors on online-based tests. He found that students from the department of computer engineering were observed to have obtained the highest score. And undergraduates with a technology major possessed a comparative advantage in obtaining better scores because they were more inclined to adopt a computer-based environment. Furthermore, Moradi *et al.*'s study supported this assertion, claiming that students in physics courses had high levels of engagement and satisfaction with online teaching modules, and students who used online modules performed significantly better than those who did not [110]. Moreover, the characteristics of online physics courses may also assist in explaining this result. Physics laboratories are an important part of physics courses, even some hands-on experiments are implemented in independent laboratory courses. Novel physics labs have become more prevalent in physics education over the last decade [20]. A college-level physics course's online versus face-to-face delivery was examined in a previous study, whose outcomes demonstrated that learners were satisfied with the online course. The integration of multimedia content and engaging exercises, such as simulations and games, within an online physics course has been found to be positively influential in the promotion of student motivation and learning outcomes [111]. Students can adapt well when in-person laboratory procedures are shifted online during the COVID-19 pandemic, and remote laboratories and virtual laboratories are used in physics courses [83,84]. A recent study compared students' perceptions of experimental physics before and after the COVID-19 pandemic and found that students' perceptions did not significantly decrease [24]. Furthermore, students perceived higher learning success when they gathered data on their own in the online physics experimental course [20]. Thus, it was surmised that these experimental activities may contribute to the enhancement of students' motivation for learning, enriching classroom activities, and providing students with a better experience. The majority of the theoretical courses in ERT, such as language and other liberal arts courses, were mainly led and lectured by teachers during the whole process and lacked students' active participation in classroom activities. Even the delivery of some liberal arts courses in ERT was conducted synchronously or asynchronously through the application of online video resources. A college-level physics course's online versus face-to-face delivery was examined in a study. The outcomes demonstrated that learners were satisfied with the online course [112]. Consequently, it was hypothesized that the greater degree of flexibility offered by the asynchronous online course was a contributing factor to the higher level of student satisfaction. Furthermore, the integration of multimedia content and engaging exercises, such as simulations and games, within an online physics course has been found to be positively influential in the promotion of student motivation and learning outcomes.

B. Gender differences in students' perception of ERT experience

In response to the second research question, it was found that male physics students reported considerably higher extraneous cognitive load in ERT than female physics students based on the assessment of their flow experiences and cognitive load scores. The extraneous cognitive load is caused by the instructional design, whereas the germane cognitive load is related to knowledge acquisition [113]. Since female physics students rated less extraneous cognitive load in ERT, the presentation of learning materials and organization of information adopted in ERT may have a less negative impact on females' learning in ERT. Findings in the previous studies regarding gender differences in online learning tended to be inconsistent [96,97,106,114–116]. Some reported that female physics students had stronger self-regulation [114] and were more persistent and engaged than male physics students [97], resulting in higher learning outcomes than male physics students, while male physics students tend to hold more stable positive attitudes toward online learning [115]. A study reported that males had significantly less cognitive load when learning through the mobile learning platform [106]. Another study found that high school female students were more likely than males to have online learning ineffectiveness in online experimental courses [96]. Furthermore, there were also no significant gender differences in the learning satisfaction of online millennial learners [116]. The gender difference in students' flow experience and cognitive load in the ERT environment in the present study supports part of the previous research results [114]. It should be admitted that there are some different characteristics between ERT and online learning. The present research on gender differences extends the learning environment from conventional online learning to specific ERT. The result provides some ideas on how to improve the learning of students of different genders in ERT.

C. Education level differences in students' perception of ERT experience

As for physics undergraduates and postgraduates, postgraduates acquired better flow experience than undergraduates. Previous studies pointed out that postgraduates preferred the online learning method to the traditional face-to-face method, which led to better online learning outcomes for postgraduates than undergraduates [102]. It has been pointed out that undergraduates were easily distracted by visual stimuli such as web videos or they did not dedicate enough time to seriously engage in online courses [101]. In the present study, although the p value did not reach a significant level, physics postgraduates still showed a little stronger engagement and learning control than physics undergraduates in three of the flow experience constructs. It can be seen that irrelevant external stimuli might have less impact on postgraduates exhibiting a higher level of self-control, who might subsequently focus on and control their learning behaviors. Furthermore, prior research revealed that postgraduates favored online learning over conventional face-to-face learning, which improved postgraduates' online learning outcomes relative to undergraduates. As a result, graduates in this study reported having less flow experience. In addition, the cognitive load did not differ significantly between physics students at different educational levels. The extraneous cognitive load relates to inappropriately designed instructional materials and can be influenced by instructional designers. The postgraduate and undergraduates participated in physics courses with similar curriculum designs, learning materials, and teaching strategies during ERT. The result reveals that the extraneous cognitive load of physics students in ERT was independent of educational levels. Both physics undergraduates and postgraduates had lower extraneous cognitive load and higher germane cognitive load than the average of all participants. It suggested that there was less negative impact for physics students when face-to-face teaching was urgently switched to ERT mode and physics majors perceived the ERT experience more positively, regardless of graduate or undergraduate levels.

Strictly and scientifically speaking, ERT implemented in this study exists in a slightly different environment compared with online learning. In contrast to online learning, ERT is a "totally online mode" [117]. This teaching mode in ERT is different from the adjunct online learning mode that uses the Internet to assist traditional face-to-face education. It is also different from blended learning which considers online learning as an integral part of traditional face-to-face instruction. In the context of ERT, teaching and learning activity is not only completely remote but also sudden and mandatory [118]. When placed in this complex, vulnerable, and emotionally affected educational environment, students face many challenges in their learning [119]. In a COVID-19 environment, students' perceptions of ERT may be dissimilar from how they previously perceived online education. This study is an exploration of ERT learning in the very emergent and compulsory periods, reflecting the differences in flow experience and cognitive load of students in physics and nonphysics groups, as well as in groups with different genders and education levels.

VII. CONCLUSION AND IMPLICATION

The purpose of this research was to study the perception of physics and nonphysics students regarding their ERT experience. Findings from an investigation on students' flow experiences and cognitive loads during ERT supported that physics and nonphysics students' different perceptions of their ERT experiences. Students studying physics reported higher flow experience, as well as less significant cognitive load. There is a significant gender disparity in cognitive load among physics students, demonstrating that female physics students evaluate their extraneous cognitive load higher than that of male physics students. While physics students at undergraduate and graduate levels did not significantly differ in their flow experiences or cognitive load.

To enhance the efficacy of physics teaching, relevant insights could be provided by the current study. First, the study revealed that physics students had a more suitable experience with the course's flow than nonphysics students, suggesting that the ERT features of physics courses, such as online experiments and technology-supported activities, may be advantageous to physics students' learning. The physics curriculum tends to comprehend these traits from a broader perspective, matches students' expectations for involvement in class, fun, and control, and encourages higher engagement in learning. Second, the utilization of online experimental tasks may have made the transition for physics students from face-to-face class to ERT easier as they rated a lower extraneous cognitive load and a higher germane cognitive load in ERT than nonphysics students. Furthermore, students are able to concentrate on learning by reducing the cognitive load caused by the transfer and fostering course continuity when a transfer to ERT is necessary. The research outcomes subsequently indicate that the extraneous cognitive load was substantially higher for male physics students than for female physics students. Considering that the instructional design is what generates the superfluous cognitive load, the way learning materials are presented and how information is organized in ERT may have a less detrimental effect on the level of females' capacity to comprehend. Subsequently, teachers can provide specific instruction to students to lessen the detrimental impacts of teaching mode shifts in ERT according to these disparities between male and female physics students. Teachers should offer support and prompt psychological assistance to students of all genders as necessary.

VIII. LIMITATION AND FUTURE RESEARCH

This study has certain restrictions as well. On the one hand, participants in the present study were from only one university in the People's Republic of China. On the other hand, the data collection is from students' self-reports after class and it failed to capture students' current states of flow and cognition in the ERT classes. Certain limits exist on the veracity of the research findings because it does not accurately reflect the students' actual situation. Furthermore, the implementation of a retrospective pre-test-post-test approach would more reliably discover pertinent changes brought on by the COVID-19 pandemic, but there were no previous or longitudinal data for comparison with the observed variables in this investigation. Additionally, the study focuses on the perceptions of students, rather than on objective measures of learning outcomes or performance.

In the future, studies could positively gain from having a wider participant pool, including students from various institutions and majors. Furthermore, it is necessary to capture the students' experience of ERT promptly with the help of educational neuroscience or artificial intelligence technology. Some research methods, such as classroom observation or interviews, could be supplemented to confirm participants' actual thoughts, which will be helpful to better improve student learning in ERT. Additionally, it is worth exploring the relationship between students' perceptions of ERT and their actual learning outcomes.

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APPENDIX: THE FLOW EXPERIENCE SCALES AND THE COGNITIVE LOAD SCALES

Flow experience scale.

Flow experience	Items
Enjoyment	The learning material inspires my curiosity in emergency remote teaching. The learning material is enjoyable in emergency remote teaching. The learning material is interesting in emergency remote teaching. The learning material is unpleasant in emergency remote teaching.[a]
Engagement	I deeply involve myself in the learning material in emergency remote teaching. During the learning, I will be distracted in emergency remote teaching.[a] I work hard to be engaged in the learning material in emergency remote teaching. I am concentrated on the learning material in emergency remote teaching.
Control	I feel frustrated in the process of the learning in emergency remote teaching.[a] During emergency remote teaching, I am skilful and able to monitor the learning. I know how to operate or participate in the learning activity in emergency remote teaching. In emergency remote teaching, the presentation or organization of the learning contents is convenient for me to operate or participate in.

[a]Reverse item.

Cognitive loads scale.

Cognitive loads	Items
Intrinsic cognitive loads	The learning content is very difficult in emergency remote teaching. The learning content is very complex in emergency remote teaching. The learning content is not easy to be comprehended in emergency remote teaching The learning content is beyond my competence in emergency remote teaching.
Extraneous cognitive loads	I do not like the presentation or organization of the learning material in emergency remote teaching. I am not interested in the presentation or organization of the learning material in Emergency Remote Teaching. The presentation or organization of the learning material requires strenuous efforts when learning in emergency remote teaching. The presentation or organization of the learning material is not helpful for me in emergency remote teaching.
Germane cognitive loads	The learning material helps me concentrate on the learning in emergency remote teaching. The learning material helps me work or learn hard in emergency remote teaching. I am willing to put more efforts on the learning in emergency remote teaching. I am willing to spend more time on the learning in emergency remote teaching.

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