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บทความวิจัย

การปฏิรูปการเรียนรู้ของหลักสูตรปฏิบัติการในห้องแล็บระดับอุดมศึกษาเพื่อส่งเสริมความยั่งยืนในยุคหลังการระบาดของโรคโควิด 19

Reform of Laboratory Courses Teaching in Higher Education to Enhance Sustainability in the Post COVID-19 Era

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บทคัดย่อ

การระบาดของโรคโควิด 19 เป็นอุปสรรคและความท้าทายของทำให้หลักสูตรการปฏิบัติการในห้องแล็บในขณะเดียวกันก็ส่งเสริมให้เกิดการการพัฒนาวิธีการสอนที่หลากหลาย และมีการพิจารณาไตร่ตรองวิธีการจัดการเรียนรู้การปฏิบัติการในห้องแล็บระดับอุดมศึกษาอย่างลึกซึ้งด้วย ในทางกลับกัน สื่อการสอนที่น่าเบื่อและคงเดิมกับแบบการทดสอบอย่างเป็นทางการเชิงทฤษฎีก็ส่งผลให้ผู้เรียนเฉื่อยชาและมีทัศนคติแบบขอไปทีต่อเรียนแบบทดลองด้วย การเผชิญหน้ากับอนาคตที่ไม่แน่นอนผนวกกับความเมินเฉยของผู้เรียน ทำให้จำเป็นต้องปฏิรูปหลักสูตรอย่างเร่งด่วนเพื่อเสริมสร้างความยืดหยุ่น ความสามารถในการฟื้นตัว และผลสัมฤทธิ์การเรียนรู้ไปพร้อม ๆ กัน แนวทางการออกแบบหลักสูตรการเรียนรู้ที่สำคัญ คือ การใช้วิธีการสอนและสื่อการเรียนรู้ที่หลากหลายเพื่อส่งเสริมการพัฒนาที่ยั่งยืนในหลายมิติอย่างต่อเนื่องของระดับอุดมศึกษาภายใต้ความปกติใหม่ งานวิจัยได้ออกแบบรายวิชาการวิเคราะห์เครื่องมือการทดลองและสอบถามมุมมองและข้อแนะนำจากผู้เรียนด้วย จากนั้นจึงเปรียบเทียบผลการสอนกับการเรียนรู้ครั้งที่ผ่านมานับตั้งแต่เกิดการระบาดของโรคโควิด 19 ผลการวิจัยชี้ให้เห็นว่าหลักสูตรที่ออกแบบใหม่นี้ทำให้ผู้เรียนมีผลสัมฤทธิ์ทางการเรียนรู้ดีขึ้นทั้ง 3 ด้าน ผู้วิจัยมีความมุ่งหวังว่ารูปแบบการเรียนรู้นี้จะได้รับการพัฒนาอย่างต่อเนื่องเพื่อสามารถนำไปใช้อย่างกว้างขวางในสาขาวิชาอื่น ๆ ได้

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Abstract

The COVID-19 pandemic has brought many difficulties and challenges to laboratory courses, but also promoted the development and prosperity of various teaching methods and made the position of laboratory instruction in higher education contemplated deeply. On the other hand, the monotonous and constant teaching materials and the formalized and theorized examination form have resulted in students' inertia and perfunctory attitude toward the experiment learning. Facing unpredictable futures and students' indifferent mentality, we urgently need to redesign the curriculum to enhance flexibility and resilience, meanwhile, ameliorate educational achievements. It is an important guiding principle of curriculum design to utilize diversified teaching methods and resources to continuously promote the multi-dimensional sustainable development of higher education under the new normal. In this work, an instrumental analysis experiment course was redesigned, and the students' views and suggestions on the new curriculum were inquired. Then the teaching effect was compared with that of the previous courses since the COVID-19 pandemic. The results indicate that the new curriculum design enables students to achieve better learning results in the three domains of learning. We anticipate that this teaching model will be improved continuously to be generalized to a more extensive educational field.

Keywords: higher education, instrumental analysis, integration, Post-COVID-19 Era, sustainability

Introduction

Chemistry is innately a laboratory science and laboratory instruction plays an irreplaceable role in the whole training process (Elliott et al., 2008). The National Science Teachers Association emphasizes that learning in the laboratory can make abstract ideas tangible for students, help develop problem-solving skills, and even foster positive attitudes (Galloway et al., 2015). Unfortunately, the COVID-19 pandemic has presented numerous challenges for every segment of the higher education system, such as hiatus in face-to-face teaching and difficulty in using extramural resources, especially for laboratory courses (Dukes lii, 2020). Diverse solutions, including virtual simulation experiments and remote education systems (Songkram et al., 2021), have been generally applied to ensure that students' learning was not compromised, but there are still many problems (Chans et al., 2022). Recently, abundant studies have proved that pure online education is not able to achieve the same effect as offline teaching, and is prone to cause more anxiety in students learning practices and lead to more isolation in their learning process (Akramy, 2022). Online education promotes learning that is one-dimensional in scope and cannot effectively provide students with what they need. It is also difficult for students to learn without the assistance of face-to-face instruction and communication, and students often do not take the initiative to contact teachers when they encounter difficulties in online courses (Reese, 2014).

With the improvement of the epidemic situation in some countries and regions, students have returned to campus. They regain opportunities to enter the laboratory, participate in experimental courses offline, and even practice in factories and enterprises off campus. It seems that everything is restoring

gradually to the original state before. However, the impact of COVID-19 on higher education is far-reaching. Adhering to “the new normal” of experimental instruction in the post-COVID-19 era needs dual reflections brought to higher education: on the one hand, university educators should advocate multidimensional sustainable higher educational philosophy; on the other hand, they should integrate various teaching methods, tools and resources to reduce the negative impact of the epidemic on teaching. We urgently need more flexible and resilient education systems to respond to the challenges of emergencies and more integrated teaching methods to ensure teaching quality. Hence redesigning curricula is becoming increasingly necessary.

Today's learners need collaboration, freedom to explore and create knowledge, and authentic audiences to increase participation and activity (Murphy et al., 2011). Therefore, instructors should provide students with an experience that can promote both autonomy and community, from which both teachers and students can benefit (Reese, 2014). The combination of asynchronous and synchronous teaching is an efficient way, both of which have their advantages and disadvantages. Asynchronous learning enables students to learn factual and conceptual knowledge, while the synchronous process focuses on the construction of procedural and metacognitive knowledge. A balanced online environment should provide a blend of both asynchronous and synchronous opportunities, which promote communication and collaboration among classmates and instructors (Akram et al., 2021; Fabriz et al., 2021). We can readily employ technical assistance since a growing number of platforms provide an ability to integrate asynchronous and synchronous teaching, and can even effectively combine offline teaching, such as Voov Meeting™ and Rain Classroom™ can record the synchronous interaction and communication for asynchronous playback.

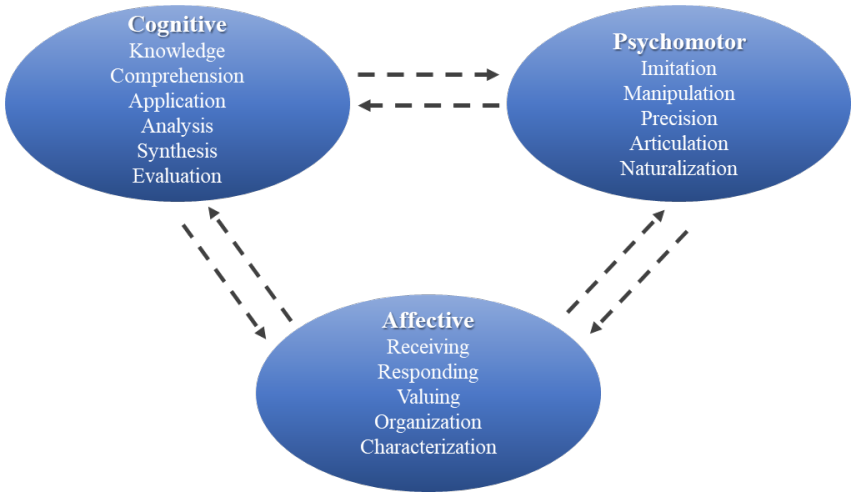
It is another effective approach to fully promote the sustainable development of higher education to construct a realizable framework for sharable learning resources and enable students to obtain core competitiveness through establishing a school enterprise cooperative education model. As early as before the outbreak of the epidemic, many instrument manufacturers contacted relevant principals. Some hoped to receive opportunities to share practical instances and functional protocols encountered in their work with undergraduates, and others attempted to take advantage of advances in technology to offer alternatives to those hazardous experimental operations. Higher education is inseparable from the support of enterprises with practical experiences and abundant resources after the epidemic. Students require these channels to broaden their horizons and cultivate skills that include but are not limited to cultural and global awareness, self-direction, risk-taking and creativity, communication, reflection, and real-world applications of knowledge.

The COVID-19 pandemic not only makes students' learning styles transform but influences their psychology and emotions extremely. Numerous reviews have detailed research on the affective domain in science education in the past 30 years. The research reports specific to chemistry devoted to affective learning include developing assessment tools to measure chemistry self-concept and attitudes toward chemistry (Bauer, 2008; Reardon et al., 2010; Xu & Lewis, 2011). Subsequent research has used these assessment tools to investigate the effectiveness of new pedagogical reforms(Chase eta al., 2013) and

demonstrate the necessity of attending to the affective domain in chemical education (Brandriet et al., 2013; Chan & Bauer, 2014). We emphasize that meaningful learning requires the integration of cognitive and affective learning with the psychomotor again. A group of researchers led by Benjamin Bloom formulated the best-interpreted taxonomy of learning domains in 1956, in which the domains of learning can be categorized as cognitive domain (knowledge), psychomotor domain (skills), and affective domain (attitudes) (Hoque, 2016). Achievements in the cognitive domain include the knowledge obtained in the experiment; achievements in the psychomotor domain include the skills acquired from experience, and achievements in the affective domain include students' attitudes and emotions toward the experimental and learning atmosphere (Hensen & Barbera, 2019).

Figure 1

The three domains of learning and their activities at different levels



There have been fewer studies on how to integrate various teaching methods and resources so that undergraduates can obtain better experiences in experimental learning and the sustainable development of higher education can be realized ultimately. Based on the above considerations, this article attempts to redesign a new instrumental analysis experiment course (IA-EC) to enhance the sustainability of experimental teaching in higher education in the post-COVID-19 era.

Medtodology

1. Overview

The present study mainly consists of two parts. For one thing, the curriculum was reconstructed to solve several problems existed in the latest survey. For another, students taking different IA-ECs during the COVID-19 pandemic including the new IA-EC were given a series of questionnaires and sample interviews, and they also were provided with an opportunity to freely discuss their reasoning. The learning outcomes

and the perspective of the students in three domains of learning (cognitive, affective, and psychomotor) were collected and analyzed.

The CEQ (Course Experience Questionnaire) scale was created by Johnson when he surveyed Australian university graduates in 1996, which asks graduates to rate their agreement with each of 25 items, including the quality of teaching, the clarity of the goals and standards, the level of the workload, the nature of the assessment, and the extent to which generic skills are embedded in the course. Although its measurement dimensions can be adjusted according to the actual situation of each school, the three core dimensions of good teaching, basic skills, and overall satisfaction with curriculum experience can not be ignored. This scale was modified appropriately according to the reality, which includes 37 items distributed among 7 subscales (good teaching, clear goals and standards, appropriate workload, appropriate assessment, generic skills and competencies, university support, resource support off campus), and the specific items are presented in

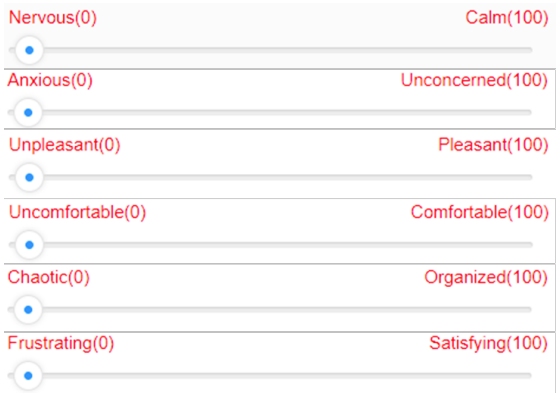
The questionnaire employed in this study and student free-response examples:

Table 1 The 37 items were answered on a five-point Likert scale: 1—strongly disagree, 2—disagree, 3—neutral, 4—agree, and 5—strongly agree. The higher the questionnaire value, the better the perception of the course experience. The answers provided were statistically treated and analyzed, considering the evidence of associations between the learning quality and the perceptions described by the CEQ scales (Ramsden, 1991; Nogueira et al.,2021).

Few chemistry laboratory studies have included affective measures. This shortage of studies may be partially due to the scarcity of affective measures that have been designed for or tested in, the college laboratory setting. To provide measures for use in this environment, several existing affective scales were adapted for this new context by Jack Barbera (Hensen & Barbera, 2019). It consists of a set of Likert scales and slider scales. The slider scale requires respondents to complete the questionnaire by drawing the bar to the corresponding value. In terms of the function merely, they are similar and collect values indicating the degree. However, the latter creates a fresh answering experience, which is more interactive with the participants. The version of each scale was further modified to make them available to this study as presented in Table 2 and Figure 2. And before data from the scales was utilized, evidence was provided for the validity and reliability of the data generated from them. The questionnaire survey and interview are conducted in Chinese through a combination of online and offline.

Figure 2

Questionnaire on students' anxiety and emotional satisfaction (only part of these items is shown)



2. Participants

This research was conducted using a quasi-experimental design. It involved 260 undergraduates and 9 teachers (including TAs) who were enrolled in five IA-ECs at Tsinghua University (THU) and Harbin Institute of Technology (HIT). From this population, 67 who intend to obtain engineering degrees in HIT attended IA-EC1 and 43 who intend to obtain science degrees in HIT were registered in IA-EC2. Likewise, 25 and 39 who intend to obtain science degrees in THU participated in IA-EC3 and IA-EC4 respectively. This semester, a total of 86 undergraduates from four schools and departments of THU have joined the new IA-EC. They had the option to provide informed consent, and only those participants who consented are represented in the data.

3. Course Description

IA-EC1 was set up by the school of chemical engineering and chemistry of HIT for the engineering sophomores, which existed as a supplement to the compulsory theory course. IA-EC2 was organized by the school of chemical engineering and chemistry of HIT for the science sophomores. This course is carried out independently and required to complete comprehensive experiments. Both courses use online lectures and virtual simulation platforms. IA-EC3 and IA-EC4 were established by the department of chemistry of THU for sophomores and juniors of this department and used online teaching and video learning. These two courses are one credit and two credits for students with different training programs respectively. The main contents of these IA-ECs include the basic methods of instrument operation, including the operation of infrared spectrometer, UV-Vis spectrophotometer, gas chromatograph, liquid chromatography, atomic absorption spectrophotometer, electrochemical workstation and other instruments; establishment and optimization of analytical methods, including sample pretreatment method, instrument condition optimization and experimental data analysis. During the COVID-19 pandemic, these instructors adopted the online teaching mode and provided current students with data collected by students in previous years and assigned them simulations to allow them to collect their own data. The examination form has also been adjusted: the scores are accumulated by the online theoretical examination and the writing of experimental reports. Each course was supervised by several teachers and corresponding teaching assistants responsible for different experiments.

Results

Overall design and reform

The basic instrument operations in the undergraduate training program have not changed. The curriculum is divided into seven units, and the curriculum content is selected on cutting-edge scientific research to increase innovation, comprehensiveness, and interest. The first six units include mass spectrometry analysis, electrochemical analysis, molecular and atomic spectral analysis, chromatographic analysis, nuclear magnetic resonance (NMR) and electron spectroscopy analysis, electron microscope and atomic force microscope (AFM), and X-ray diffraction. The last unit consists of four comprehensive experiments. Each unit contains different amounts of experiments, for example, the electrochemical analysis unit incorporates four experiments: cyclic voltammetry (CV) to measure the concentration of specific proteins in serum, electrochemiluminescence (ECL) to detect cell surface proteins, electrochemical workstation to study the electrochemical performance of a lithium-ion battery, and anodic stripping voltammetry (ASV) to determine trace heavy metal ions in water. Each student should choose experiments following their own demands and interests in every unit. At least one experiment in each unit should be selected, and a total of 12 experiments need to be completed. The comprehensive experiment part is based on several selected references. Student groups should determine which material performance tests are required and finally complete two comprehensive experiments with the help of the teaching assistant. The overall design of the new curriculum is shown in Figure 3.

1) Before class: Asynchronous video learning and virtual simulation operation allow each student to participate in the operation effectively.

Due to the limited availability and high maintenance cost of analytical apparatus, even though we try to reduce the capacity of each group, it is impossible to ensure that everyone can carry out the entire experimental operation training in class. Avoiding time-consuming review in class and understanding the operations more clearly can be realized through preview in advance. And virtual simulation operation ensures the fine experimental experience to the greatest extent and prevents artificial damage to the instrument.

2) In class, the problems encountered in actual operations combined with relevant theories are embedded in procedural records to facilitate the transfer of knowledge. Students have opportunities to attend synchronous lectures and visit professional institutions.

Firstly, we should offer timely and effective feedback to the problems in the learning process to improve learning efficiencies in class, such as a lack of some theoretical knowledge and the operation that causes the instrument to report errors. Students and TAs submit these questions to the platform. Teachers can reply to unsolved problems in class on the platform after class, which can not only improve the communication between teachers and students but also enable students to recall relevant knowledge at any time in the future. In addition, we also invited veterans from analysis and testing institutions and the R & D department of pharmaceutical enterprises who work on the front line to interpret the necessity of learning these instruments and precautions for operation. We expect to obtain their consent to visit, and even internship opportunities further.

3) After class, an online Q & A platform acquaints teachers with students' emotions and requirements to adjust at any time.

After the end of the general experimental course, there is no contact between students and instructors, which creates an obstacle to the communication between teachers and students. Using the discussion platform of the online school and the question and answer function of the third-party software, teachers can know students' learning difficulties and make timely adjustments to the curriculum according to students' needs.

4) The students can be awarded the "Large-scale Instruments Operation Certificate" that endows credence in their careers *via* advanced examinations.

The advanced training link is specially designed for students who can acquire more comprehensive experimental skills. They can apply for training in accordance with their interests and employment requirements. We provide further operation guidance on specific large-scale instruments and issue certificates to those who pass the assessment. We believe that this is conducive to facilitating the integration of higher education with future employment and equips students with professional skills in relevant industries.

5) The assessment takes the form of flipped classroom. Ultimately, excellent students in comprehensive evaluation can be recommended as TAs for the subsequent courses, which forms a virtuous circle.

We believe that students review the principles of the instrument through regular quizzes, and complete a relatively systematic knowledge assessment in theoretical courses. In addition, it is arduous to establish equitable evaluation criteria and supply sufficient pieces of equipment to organize experimental examinations uniformly. Based on the above considerations, we chose the flipped classroom test formation, which not only allows students to systematically review the instrumental working principle but also further strengthens their memory in the process of simulation guidance. High-achieving students also have the opportunity to be recommended as teaching assistants for the subsequent courses.

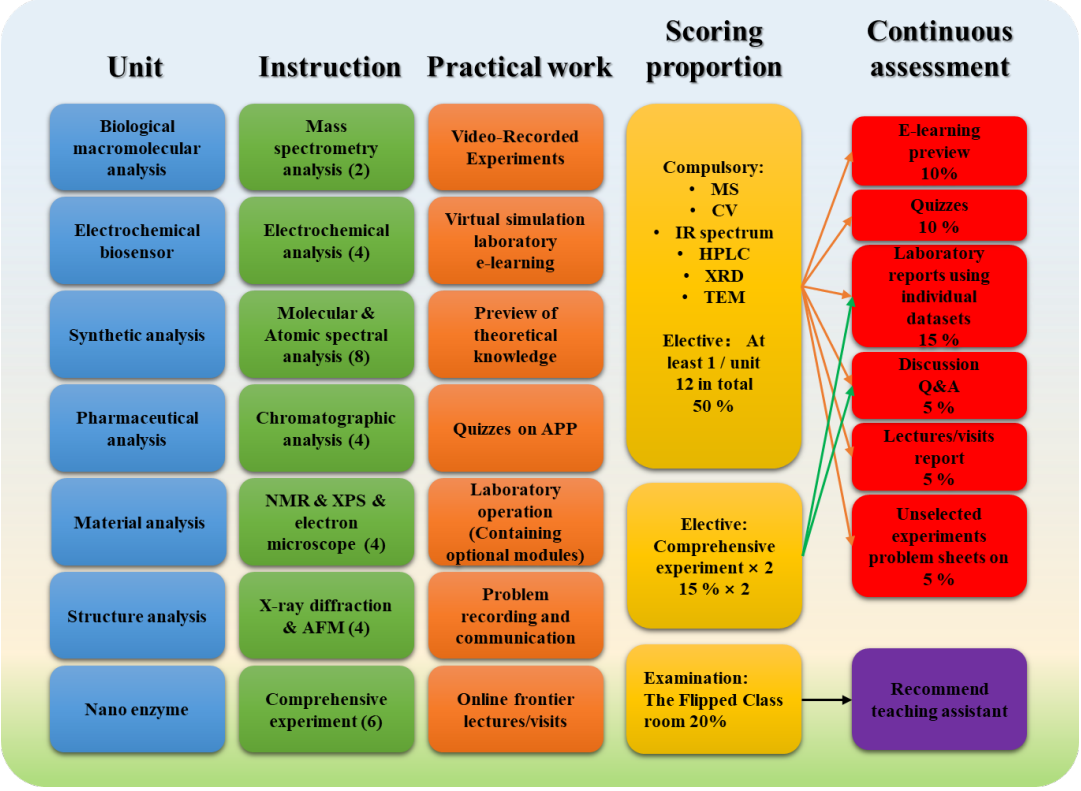
Students' perceptions and responses

Confined by the experiment attribute, it is impossible to send certain reagents and/or pieces of equipment for students to complete at home, the statistical analysis of questionnaire data demonstrates that experimental experience generated by online teaching, video viewing and virtual simulation operation was very narrow during the COVID-19 pandemic. Exemplars of the free-response explanations gathered from students concerning their perceived value are provided in Table 3. A significant number of the student free responses indicated that the learning process is formalistic and perfunctory, and the experimental content has hardly changed for several years, which is far removed from requirements in the new era. These courses simply focus on data collection and processing, which inevitably leads students to invest excessive ineffective efforts in the experimental report due to the obvious correlation with the final grade. Students felt they learned less in the virtual environment and found it challenging to correlate the acquired data with experimental procedures and subsequent lab reports. In general, the experimental operation techniques have not been improved. There appeared two main views among these students: some students

noted that they got an overwhelming feeling of anxiety because of unclear expectations with respect to the report writing and their inability to ask questions of their instructor or TAs, and the final learning effect was not satisfactory. For other students, laziness due to the scarcity of supervision makes them fail to achieve the desired results.

Figure 3

Schematic module overview. The numbers in brackets and percentages represent the number of experiments included in these units and the proportion of corresponding parts in the total score, respectively. Each experiment includes all practical works of learning and assessment. The learning and operation processes were recorded synchronously in the third-party application.



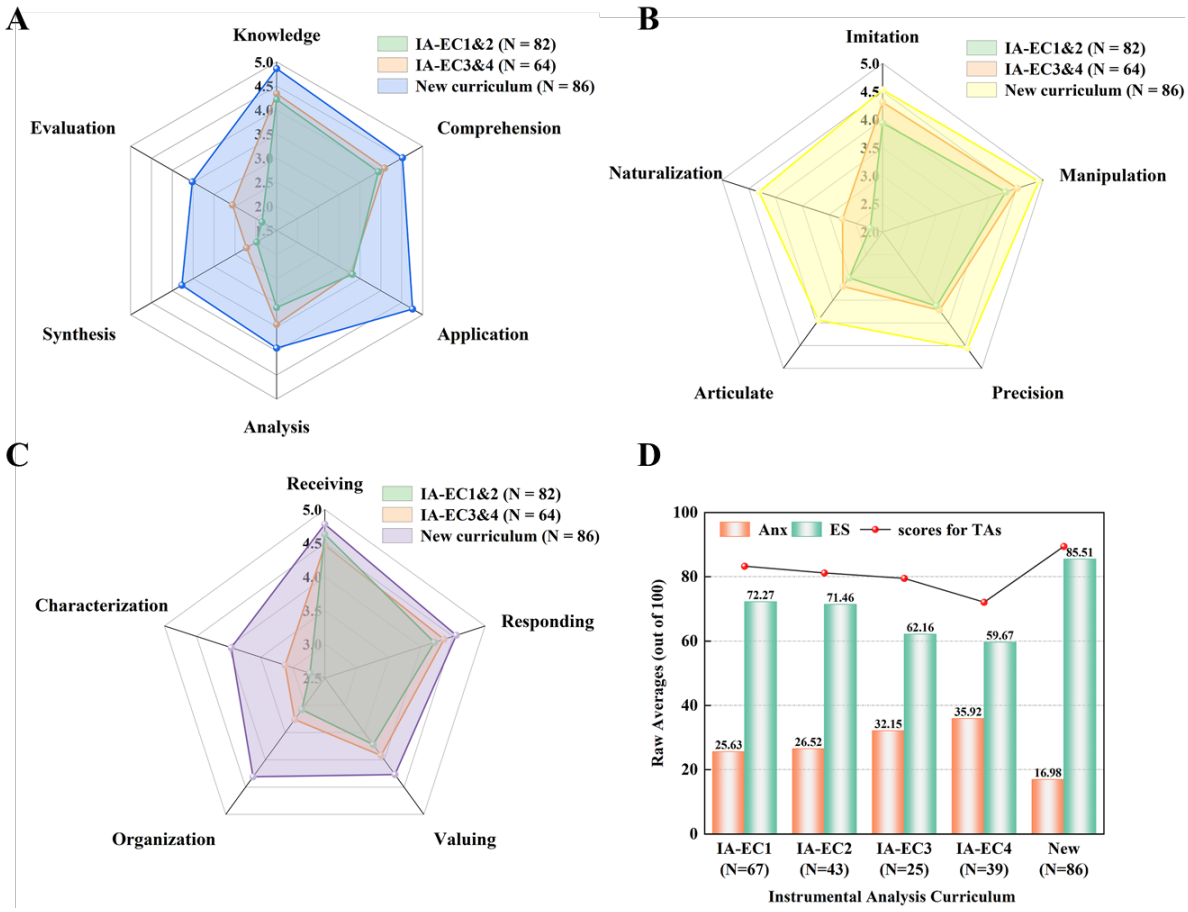
A significant number of the student free responses indicated that the content arrangement and link design of this new curriculum was of high value to their learning experience. Specifically, the students noted that the single pedagogy is inadequate when intending to gain practical experience in chemical laboratory skills and instrument use. As the students pointed out, previewing through video and simulation operations in advance can help understand the purpose of the experiment and background concepts. Some students indicated that practical experience acquired from in-person experiments and veterans aided in the understanding of the theory of instrumental analysis. The subsequent laboratory experiments and lectures provide an effective avenue to connect the information learned in the classroom with its practical applications and usage. Alternatively, others focused more on how these hands-on experiences affect their

future job-hunting. They said that the involvement of enterprises allowed them to notice the employment prospects in this profession, and the exam format and the opportunity to obtain certificates made them study more seriously and improve their practical ability.

Affective measurement demonstrates that students' emotional satisfaction is significantly improved accompanied by a decrease in anxiety in each learning segment of offline courses. Some students mentioned the psychological benefits the course offered. Another student noted that coordination of various parts made the course seem less isolating, which in turn enhanced their general motivation. Analysis of the subjective will showed that over 97% of students have a positive attitude toward this course, appreciate the acquisition of meaningful knowledge, and highly recommend this course to other students. In addition, we pay particular attention to the function and students' personal evaluations of TAs. The result indicates that timely personal guidance and feedback from TAs can contribute to further optimizing the course experience.

Figure 4

The raw average of students' perceptions on three curricula via one Likert scale across the three domains of learning (A) cognitive, (B) psychomotor, and (C) affective. (D) Raw averages for the affective scales in five subgroups. The point-line chart represents the average emotional satisfaction with each TAs. (Anx, anxiety; ES, emotional satisfaction; N = number of valid questionnaires)



Conclusions

We have taken instrumental analysis experimental courses as models to explore a design principle of laboratory courses, in which the students' emotions and career development were comprehensively taken into account, to promote the sustainable development of higher education in the post-COVID-19 Era. In the post-COVID-19 era, “the new normal” of higher education requires educators to integrate multifarious teaching methods and resources and to pay more attention to sustainability throughout the whole teaching process. The integrated and sustainable education concept is mainly reflected in the following four aspects. The first is integrating various electronic information technologies to promote the sustainability of the learning process. Students' individualized questions have electronic records, which can be retrieved and inquired at any time. The second is comprehensive information fusion for sustainable appraisal of students' learning outcomes and teachers' teaching effects. Data-based and procedural records can provide a more comprehensive assessment system to prevent students from “involution” on experimental reports. The third is paying more attention to the sustainability of students' psychology. Teachers' presentation time and appropriate synergism of different teaching methods can affect students' psychological state, thus teachers should show solicitude for the students' emotional changes in the learning process. The fourth is the collaboration of multi-channel learning resources to promote the sustainability of career development. In addition to universities, scientific research institutes and enterprises should participate in undergraduate education and provide platforms to broaden their horizons, which has guiding significance for students' future career choices and research directions.

Through the above analysis, we believe that higher education should take full advantage of integrated education and focus on sustainability to cultivate adequate talents who make positive contributions to social development in the post-COVID-19 era. Because the great majority of science and engineering undergraduates tend to enter scientific research positions, they need more solid theoretical foundations and stronger practical abilities, which are inseparable from quality experimental education. The changes brought about by the pandemic will exert a profound and lasting influence on the laboratory courses, and accelerate the iterative education objectives and methods to meet the requirements of the new normal. Preliminary results have been achieved but we still have a long way to go. We anticipate that this teaching model will be ameliorated continuously to be generalized to a more extensive educational field.

The questionnaire employed in this study and student free-response examples:

Table 1

The items and subscales of the modified CEQ used in this study.

No.	CEQ Items
	Good Teaching Scale
1	The instructors of this course motivated me to do my best.
2	The instructors put a lot of time into commenting on my work.
3	The instructors made a real effort to understand the difficulties I might be having...
4	The instructors normally gave me helpful feedback on how I was going.
5	My lecturers were extremely good at explaining things.
6	The instructors worked hard to make their subjects interesting.
	Clear Goals and Standards Scale
7	It was always easy to know the standard of work expected.
8	I usually had a clear idea of... what was expected of me in this course.
9	I usually had a clear idea of what I was doing during the course.
10	It was often hard to discover what was expected of me in this course.
11	The instructors made it clear right from the start what they expected from students.
12	Feedback on my work was... only in the form of marks or grades.
	Appropriate Workload Scale
13	The workload was too heavy.
14	I was generally given enough time to understand the things I had to learn.
15	There was a lot of pressure on me to do well in this course.
16	The sheer volume of work... couldn't all be thoroughly comprehended.
	Appropriate Assessment Scale
17	To do well in this course, all you needed was a good memory.
18	The staff seemed more interested in testing what I had memorized. . .
19	The instructors asked me questions just about facts.
	Generic Skills Scale
20	The course developed my problem-solving skills.
21	The course sharpened my analytic skills.
22	The course helped me develop my ability to work as a team member.
23	As a result of my course, I feel confident about tackling unfamiliar problems.
24	The course improved my skills in written communication.
25	The course helped me to develop the ability to plan my own work.
26	The course improved my skills in presentation.
27	In class, I carefully observe the instructor's operation and try my best to imitate it
28	Through the course, I can skillfully operate at least one analytical instrument.

Table 1 (Cont.)

The items and subscales of the modified CEQ used in this study.

No.	CEQ Items
29	I can bring together all the individual parts of the course. (Skills combined and sequenced)
30	I feel some important operations have formed muscle memory.
	University support
31	My department provided the necessary hardware assistance for my experiment.
32	My academic supervisor (i.e., university training manager) was extremely supportive.
	Resource support off campus
33	The sharing of enterprise professionals is very valuable to me.
34	The opportunity to learn about various enterprises is helpful for my professional development.
	Overall Satisfaction Item
35	Overall, I was satisfied with the quality of this course.
36	I feel I have achieved my expected target.
37	I would like to recommend this course to other students.

Table 2

The items and subscales of the modified Affective Measure Questionnaire used in this study.

No.	AMQ Items
	Initial Interest-Feeling
1	I am fascinated by instrumental analysis.
2	I chose to take this experiment course because I'm interested in the topic.
3	I am excited about taking this class.
4	I am looking forward to learning more about chemistry.
	Initial Interest-Value
5	I think this course is indispensable for cultivating professional quality.
6	I think that what we will study will be important for me to know.
	Usefulness of Lab
7	This experiment allowed me to study complex problems.
8	I enjoyed the process of completing the experiment in collaboration.
9	This experiment was interesting to me.
10	I learned meaningful knowledge from this experiment.
	Equipment Usability
11	This experiment was easy to set up and operate
12	This experiment worked well
	Open-Endedness of Lab
13	It was easy to explore in this experiment
14	This experiment was too long.

Table 3

Student Free-Response Examples for Perceptions of the Value of five IA-ECs.

Number	Perceptions	Examples of Student Responses
IA-EC1	***Same value***	Online is not as interesting as personal experience, but the content of the laboratory is the same as the actual situation.
	Low value	The course content is outmoded and backward.
	Low value	Since the equipment wasn't actually in use and couldn't ask questions, I felt like I didn't fully understand the technology used in the remote lab.
IA-EC2		I find it hard to understand what I'm actually learning.
	Moderate value	Although there are various problems, online courses are the best solution that can be found at present and need to be gradually adapted.
	High value	The simulated operation provides more experience for practice and makes it easier to understand the instrument.
IA-EC3	***Low value***	Learning experiments by watching videos is not as enjoyable as working with friends.
		The online experiment class is not necessary.
		There is no guidance and supervision, and I don't know the meaning of learning.
	Moderate value	I just finished the experiment report carefully, and the learning goal is not clear.
		Video learning is freer but also leads to inertia.
IA-EC4	***Low value***	Actually, a lot of the time I'm confused about how to do things.
		I prefer to go into the lab and do it myself.
		I don't think there is much difference. The experiment class is perfunctory when the front line is off course.
	Moderate value	Applied learning is lost as technical aspects of labs were removed.
		The video provides more attention to detail than I did in the lab
New curriculum	***Low value***	There are many tasks in the course. I am anxious.
	Moderate value	The course content is rich, and it is better to provide more practical opportunities.
		I hope to cooperate with more classmates to reduce my workload and tension.
	High value	The experimental content is more cutting-edge and more in line with what I heard in lectures before.

Table 3 (Cont.)

Student Free-Response Examples for Perceptions of the Value of five IA-ECs.

Number	Perceptions	Examples of Student Responses
		I have more concrete goals to pursue: I have to study hard to get the certificate.
		The help of the teaching assistant and the communication with the teacher made my study easier.
		Lectures from enterprises made me think more deeply about my career choice.
		This form of assessment made me experience the joy of being a teaching assistant.

These responses were translated into English without changing the original meaning as far as possible.

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