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Competency Oriented Redesign and Teaching Practice of a Reduced Contact Hour Spectroscopic Analysis Course

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Abstract: Spectroscopic analysis is one of the central courses for many majors, such as chemistry, pharmacy, materials science, and the like. It helps combine chemical fundamentals with structural interpretation and further advanced studies. In the process of developing the course in question, several distinctive features are to be considered: abstract theory, rich knowledge base, integrative approach, and strong emphasis on practice. Based on the review of articles published within the last five years on the topic of spectroscopic analysis, spectral interpretation, and related courses, there were found several typical issues in this sphere of instruction, including overgeneralized syllabuses, decreasing contact hours, increasing discrepancies among student preparation levels, lack of consistency between lecture and lab courses, poor values-based course design, and heavy dependence on assessment of learning outcomes. There are also found studies that addressed undergraduates' teaching of spectral interpretation, O2O and blended course delivery, case teaching in spectral interpretation, values-based approach in pharmaceutical courses, values-based teaching in graduate courses, values integration in chromatography and spectroscopy courses, outcome-based learning in instrumental analysis, and authentic-problem-based teaching in instrumental analysis. Thus, a significant methodological basis exists that could help with further elaboration of the course in question. In view of that, based on previous findings and taking into consideration the specifics of the 32 h course, this paper suggests a competency-based course design strategy underpinned by outcome-based learning philosophy and provided with small private online courses infrastructure, grounded in values-based course design, structured according to the order of principles, spectra characteristics, their interpretation, and integration, conducted in form of problem chains and case chains, and associated with content simplification, teaching process redesign, improved assessment, teachers' professional development, and better alignment of lectures with laboratory courses.

1. Introduction

Spectroscopic analysis, which mainly includes ultraviolet-visible spectroscopy, infrared spectroscopy, nuclear magnetic resonance spectroscopy, and mass spectrometry, has played an important role in transforming the necessary organic chemistry, analytical chemistry, and other prerequisite knowledge of students into abilities to analyse structures and solve chemical problems. Previous research has suggested that this course has two key characteristics: high abstraction of theory and practice orientation of spectral interpretation. On the one hand, there are many theories, rules, and spectral patterns to be learned by students, and on the other hand, there is a need for the ability of integration to organize the scattered information and make structural conclusions based on these interpretations. Thus, the course is academically challenging but also educationally useful. For students of pharmaceutical sciences, applied chemistry, materials science, and related majors, this course not only provides necessary scientific foundations but also serves as a significant prerequisite for advanced study in natural products chemistry, TCM chemistry, pharmaceutical analysis, and other topics. In addition, it helps to complete graduation research projects, further scientific education, and so forth. In the past five years, the literature on spectroscopic analysis courses and relevant courses has provided a rather clear understanding of the main issues in this field. The main problems encountered in spectral interpretation courses included the high degree of abstraction of the corresponding theories, insufficient interaction between the teacher and the class, and inadequate interest and motivation of the students. In their teaching practice, Tang et al. aimed at making the abstract theories more comprehensible, encouraging interactions, and increasing student interests in the course through team-based outside-of-the-class spectrum acquisition and interpretation activities [1]. Ma et al., considering the concept of discipline-specific competencies blended learning, proposed the incorporation of online and offline teaching as well as spectrum interpretation after literature reading to enhance students' research awareness and discipline-specific competencies [2]. Furthermore, other articles on the subject published in Yunnan Chemical Technology and Guangdong Chemical Industry show that O2O teaching, case-based learning, and brainstorming techniques were successfully incorporated into the spectroscopic analysis and spectral interpretation classes in order to promote higher levels of participation in class, avoid the scattering of acquired knowledge, and eliminate the separation of theoretical instruction from practical work. Meanwhile, values-based education and outcome-oriented course design represent current important trends in teaching practices in this field. It is worth noting that, in recent years, the research in pharmaceutical education has shown the development of courses devoted to the spectroscopic interpretation of organic compounds used in medicines. These courses gradually move away from an exclusive focus on knowledge transmission and combine knowledge transfer with competence development and value formation [3]. Some articles discuss identification of values-based educational materials and creation of teaching plans and various assessment strategies in the courses, whereas others explore ways to integrate the value education of graduates during master's degree studies, emphasizing the importance of simultaneous development of scientific fundamentals, innovative thinking, and professional ethics [4]. There are also examples of other spectroscopy-related courses such as chromatography and spectroscopy, modern instrumental analysis, and Raman spectroscopy laboratory instruction. These courses pay more attention to the examination of educational goals, value-oriented components, and assessment approaches in relation to professional course content. Three limitations can be identified in the previous literature. First, most of the studies examine only one approach or one technique used in class (*e.g.*, flipping of the class, case-based learning, use of O2O platforms, values-based education). Secondly, even though most of the studies try to promote interest, participation, or competence in the course, the coherence of course goals, instructional content, activities, and assessment do not meet high standards. Finally, it remains difficult to overcome the problem of continuous reduction in teaching hours, especially when it is necessary to combine foundational theory, commonly used rules of interpretation, training in interpretation, and value formation, and coordinate the course with laboratory classes. Therefore, the present article is devoted to the examination of new approaches to spectroscopic analysis course design and instruction.

2. Practical Context and Conceptual Framework for Course Design in Spectroscopic Analysis

2.1. Practical Obstacles for Teaching in a Reduced-Contact-Hours Spectroscopic Analysis Course

The usual organizational structure for spectroscopic analysis textbooks and courses consists of several layers, from fundamentals and instruments to spectral characteristics, applications, and further extensions. Though such an approach works well for regular courses, it does not suit a course with limited contact hours because several issues may arise. Firstly, students can get lost in technical information regarding instruments configuration and classifications, without grasping the central logic of spectral interpretation. Secondly, due to accelerated delivery, there will be no time for students to build up their reasoning skills because they would be required to learn new material quickly by heart. The findings from recent studies, including those dedicated to undergraduate spectral interpretation, pharmacy-oriented spectroscopic courses, and application-focused organic spectroscopy teaching, come to the same conclusion: a course with reduced contact hours cannot simply reproduce traditional syllabuses. On the contrary, its content must be optimized and organized according to the core functions of such courses, which means shifting from a focus on extensive knowledge to the acquisition of essential competencies that enable one to solve disciplinary problems. In spectroscopic analysis, this involves comprehension of basics, identification of characteristic spectra, and spectral interpretation based on reasoning. This idea is supported by the problems experienced by students. Several challenges are mentioned in the literature repeatedly, namely difficult theoretical concepts, complicated spectral information, heterogeneous level of prerequisite knowledge, lack of involvement in class activities, and absence of understanding of the course's practical value. When spectroscopic analysis is perceived as a set of rules and signal patterns, students find it difficult and boring because it is more like exam-based learning than real analytical skills. However, the issue may change significantly if a connection between this discipline and relevant practices such as drug development, material testing, food safety, and science is established.

In view of these considerations, researchers pay particular attention to such aspects as student involvement, authentic contexts, and problem-based learning. Studies of blended learning, O2O approach, and problem-oriented instruction reveal that students learn better when they must interpret evidence and explain their reasoning by applying spectral data to real problems of the discipline. Consequently, the creation of a spectroscopic analysis course with reduced contact hours requires not only compression of its content but also careful reconsideration of learning purposes, activities, and approaches.

2.2. Conceptual Principles for a Unified Approach to Course Design

Given the identified problems, the exploration of teaching spectroscopic analysis demands a systemic approach and a methodological framework instead of using separate techniques. In the current paper, outcome-based education, SPOC-based blended learning, and values-based course design are considered as three interconnected components of such a framework [5]. Outcome-based education focuses on the final achievements of students, which gives a clear direction for teaching spectroscopic analysis. The focus is not on providing information about the four main spectroscopic methods; however, on making sure that students can comprehend fundamentals, recognize characteristic spectra, and make interpretations based on reasoning. Hence, OBE is crucial for creating coherence between goals, contents, activities, and assessments, as these factors determine successful competence development. SPOC-based blended learning solves the issue of limited instructional time, which creates certain difficulties in explaining fundamental knowledge and working on interpretation in class at the same time. Blended learning with the use of SPOC can redistribute learning activities by allocating low-priority ones to before-class stages, such as reviewing terminology and getting acquainted with spectral information. As a result, the remaining time in class can be devoted to explaining concepts, comparing spectra, asking questions, and discussing interpretations. Thus, the role of SPOC is not simply delivering online materials but facilitating optimal organization of class. Finally, values-based course design broadens the educational scope. For spectroscopic analysis, this means embedding scientific integrity, professional ethics, and social responsibilities in the disciplinary learning process because spectral interpretation is linked with reliability, data authenticity, quality control, environmental monitoring, and pharmaceutical safety. In addition to helping learners to understand principles of spectroscopic analysis, this dimension enables them to grasp its importance as part of a broader field of professional and social responsibility. The three components are expected to be particularly effective as a part of a unified system rather than separately introduced into a course [5]. Specifically, OBE facilitates articulation of learning intentions and logic of assessment, SPOC-based learning enables rational management of time, resources, and interactions, and values-based design bridges disciplinary knowledge and scientific ethos. Otherwise, these elements cannot be maximally helpful to teachers. Moreover, when implemented together, these components create a foundation for systematic teaching of spectroscopic analysis.

To conclude, the transformation of a spectroscopic analysis course with limited contact hours involves many things but is not confined to them. Instead, a systematic course design requires shifting from a superficial perspective to a focus on the main essence of education: comprehension, competency, and learning with a purpose. Such an understanding underpins the subsequent discussion of the course design and pedagogical practices.

3. Course Design and Teaching Practice Based on the Integration of OBE, SPOC and Values Based Education

3.1. Outcome-Oriented Design of Learning Objectives and Course Content

From the perspective of course exploration in spectroscopic analysis, learning objectives should first be defined based on the outcome-oriented approach. According to the theory of OBE, intended learning outcomes of the course can be designed in three tiers: knowledge, competence, and value formation. On the knowledge tier, students should master the basic principle of commonly used spectroscopy methods and their characteristic spectral information origin. On the competence tier, students are supposed to identify common functional groups and structural fragments, interpret simple compounds using single-spectrum and multi-spectrum interpretation and connect spectral evidence and molecular structure in a rational way. On the value tier, the course is expected to help cultivate evidence-respect, academic integrity in interpreting data, and professionalism and responsibility in connection to national development and social demand. Such learning outcomes would facilitate more efficient course exploration and provide the basis for course content design and assessment.

Based on these learning outcomes, the course content can be redesigned as follows: firstly, according to the principle of OBE, it is unnecessary to cover all parts in textbooks but instead to highlight the most critical aspects of the course for structure elucidation. Therefore, contents such as instrumental construction, sample preparation process, advanced instruments and applications, which take up much time but have low contribution rate, will be cut back. Secondly, in the context of reduced contact hour courses, there are no need for too deep analysis on spectroscopy interpretation, so a selective interpretation strategy is preferred. Specifically, ultraviolet spectroscopy is mostly for identifying conjugated system; infrared spectroscopy for distinguishing functional groups; ^{1}H and ^{13}C NMR for proton and carbon environment recognition and logical deduction about connectivity; and mass spectrometry for molecular weight and molecular formula calculation and common fragmentation pattern. Finally, few integrated interpretation tasks remain as a means of connecting students from feature identification to basic multispectral analysis.

The above-described content organization fits reduced-contact-hour courses well because they ensure the intellectual core of the course while minimizing unnecessary burdens. More importantly, the course content is in line with the educational function of spectroscopic analysis, *i.e.*, to help learners develop an effective interpretive framework for subsequent learning and research.

3.2. SPOC Supported Blended Teaching and Problem Driven Classroom Practice

In terms of the teaching process, a blended structure with SPOC-supported pre-class preparation, classroom knowledge construction, and post-class extension can be adopted. Instead of serving as a substitute for face-to-face teaching, the function of SPOC is mainly to achieve a reasonable allocation of learning tasks. Terminology, basic concepts, and common spectral information recognition can be pre-learned through video clips, guide sheets, concept cards, and self-checking quizzes. Then, students will have a prior knowledge understanding when coming to class.

In the stage of classroom teaching, emphasis will be put on tasks related to deeper understanding, *i.e.*, how and why spectral information occurs, how spectral evidence should be interpreted, and what evidence should be considered in the comparative analysis. One of the most effective instructional modes is not one-way lecturing but problem-driven learning where students are asked to answer realistic or quasi-realistic problems such as functional group recognition, presence identification of conjugated system, characteristic ion explanation, *etc*. Questions may be arranged progressively so that students learn to compare spectral evidence and rationally infer structures step by step through questioning, elimination, cross verification, peer discussions, *etc*.

The stage of post-class activity can be used to deepen and transfer learning. Post-class discussion, additional reading tasks, interpretive tasks, and reflection tasks will help integrate pre-class learning and subsequent discipline application. Previous studies about blended learning and O2O learning have shown that this allocation is beneficial to a reduced-contact-hour course, which improves class efficiency and enhances student participation and involvement.

However, a moderate degree of research awareness must also be imparted into students [2]. It does not mean that the course teaches advanced instrument operation technique, which cannot be fully covered by a theoretical course. But the target is to cultivate students' research spirit and ability, *i.e.*, questioning, evidence collection, interpretation comparison, and justifiable conclusion derivation. Scientific papers, pharmaceutical analysis or other materials about spectrum applications may thus be introduced in classes to show students that spectra do not merely contain fixed answers.

3.3. Values-Based Integration in Digital Resource Development and Assessment Alignment

The principle of values-based education is that values should be integrated into disciplinary learning, rather than simply supplemented to it [4]. The natural place of integration in a course of spectroscopic analysis is the correlation among knowledge points, case materials and value dimensions. Spectroscopic analysis is naturally connected to scientific rigour, academic integrity, professional ethics, and social responsibility because spectral interpretation is based on evidence chains, evidence reproduction, and true data analysis. Examples can be collected from Chinese scientists' contributions in spectroscopy and instrument innovation, applications in pharmaceutical safety inspection, environmental monitoring, and food quality analysis, and cases regarding responsible spectral interpretation. Values are meant to be taught not in isolation, but to enable students to understand why rigorous spectral interpretation matters in science and society.

In terms of digital resource development, it is important to ensure small amount and great value of resources. Instead of depending on full-length lecture recordings, emphasis in SPOC should be placed on developing reusable contents that support pre-class learning and class revision, such as concise concept videos, spectrum visual cards, characteristic peaks and chemical shift summary table, pre-class quizzes and brief case materials. If possible, authentic samples and common mistakes by students may be collected to form a mini-spectrum library, problem bank, and case bank for sustained assistance of blended teaching without burdening instructors. In addition, assessment should also be integrated with intended learning outcomes. Final examination is inadequate to evaluate students' achievements in spectrum interpretation, evidence utilization, and professional attitude. Therefore, the course is required to adopt a combined evaluation approach. Process-based evaluation includes pre-class preparation, quiz participation, online quizzes, class participation, case analysis, group presentation, and reflective records, while the final exam focuses less on the knowledge points and more on the rationality of interpretation and evidence use. The aspect of value formation is not necessary to give explicit indicators of slogans; instead, this aspect will be evaluated by academic norm awareness, attitude toward evidence, and teamwork quality. Lastly, coordination between the lecture course and laboratory instructions must also be ensured. Reduced-contact-hour theoretical instruction emphasizes conceptual understanding, spectrum interpretation and formation of an interpretive framework, and subsequent laboratory courses emphasize operational skills, sample preparation, and standardized analysis.

4. Reflection on Teaching Practice and Future Directions

According to the existing literature review and accumulated teaching experience, there are three most immediate positive impacts of the course design and teaching practice introduced above. First, enhanced student participation and increased learning interests are usually noted. In studies dealing with undergraduate spectral interpretation, research-awareness-oriented blended teaching, as well as O2O- and problem-oriented instruction, improved classroom engagement, active interaction, learning initiatives, and intrinsic motivation are all mentioned. Second, students' understanding of the logical sequence involved in spectral interpretation becomes more systematic, thus progressing from simple memorizing of conclusions towards judgment, comparison, and explaining of spectral data. Third, besides knowledge transmission, the course begins to promote the formation of professional identity, research awareness, and ethical consciousness. Still, several issues require thorough reflection at the same time. One of the most significant is related to changes in competency profile needed of instructors. Spectroscopic analysis already presupposes solid integrative knowledge of spectroscopy on the part of instructors; however, once outcome-oriented teaching, SPOC-supported blended learning, and value-based course design are added simultaneously, teachers should be capable of formulating learning objectives, designing digital teaching resources, organizing classroom activities, analysing learning performance, and facilitating values-based discussion. From this perspective, successful course exploration is not just revision of lecture notes; it is a comprehensive evaluation of the professionalism and collaboration skills of the teaching team. Another aspect worth considering relates to possible encouragement of superficial learning by digitalization. While SPOC-based teaching allows obvious benefits regarding flexibility and accessibility, when digital teaching resources are limited to mere uploading of slides, quizzes, and video fragments, students are easily misled about their substantial involvement in the process and may get used to extensive learning that lacks interpretive reasoning. The success of any blended learning described in previous studies is due neither to the platform itself nor even online preparation, but to thoughtful combination of online preparation with in-class activities, including flipped teaching, case analysis, and problem-solving tasks. Consequently, development of digital resources in spectroscopic analysis needs to remain focused on the formation of interpretive competencies rather than simply relying on platform functions. Another issue relates to potential risks caused by over-generalized or over-rigid values-based teaching. Spectroscopic analysis is essentially a course constructed on the basis of evidences, logic, and inference. In case if value-oriented components are separated from disciplinary issues, it may not only reduce students' acceptance but also undermine the rigorous nature of the course. Both pharmaceutical spectral interpretation and chromatography-spectroscopy teaching suggest that in order to achieve successful value-based education, it is necessary to utilize the disciplinary knowledge structure itself to integrate such components as naturally as possible through assessment, case selection, and problem situations. Put differently, values-based education cannot amount to additional stories or slogans, but should help students develop scientific thinking, academic ethics, quality and safety awareness, sustainability, and commitment to national scientific advancement in the course of analysing, judging, and expressing themselves. Yet another reflection concerns the difference between graduate and undergraduate teaching [6]. Based on available studies and accumulated teaching experience, it can be found that in contrast to advanced approaches dominating in graduate-level courses, undergraduate courses should emphasize basic principles of spectral interpretation, typical spectral characteristics, and initial integrated interpretation. In case if high-level requirements are set for undergraduate students in advance, they can lose motivation to learn; alternatively, if undergraduate teaching sticks merely to mechanical memorization, the research capabilities of these students might be limited in the future. The solution is then to lay the foundation for systematic and integrated spectroscopy knowledge and analytical reasoning at undergraduate level, which will allow to continue building the basis towards complicated spectra and cases and advanced techniques at graduate level [6]. In such situation, a teaching model involving the disciplines, innovation awareness, and professional ethics can serve as an instructive example for layering the courses. Regarding the above reflections, future course exploration in spectroscopic analysis may follow four directions. First, it is necessary to introduce a collaborative mechanism for teaching team so that different instructors take responsibilities for resource development, case design, classroom management, and coordination with laboratory classes to avoid excessive dependence on individuals. Second, a case bank and spectral library should be developed to support gradual transition to independence from textbooks and experiences of one instructor. Third, course evaluation could be conducted jointly with subsequent laboratory classes, graduation projects, and research training so that learning objectives would be identified more accurately. Finally, without imposing any extra burden on students, it is necessary to create a SPOC teaching resource system and values-based education resource pool in consideration of special features of a particular institution and disciplinary field, which will make further course exploration more stable and sustainable. All these directions are consistent with recent discussions in the literature concerning resources development, case-based teaching, integrated assessment, and continuous improvement.

5. Conclusions

In conclusion, from the above discussions about the studies on spectroscopic analysis course and its related courses, we have learned that exploration of this kind of course should transcend beyond superficial instructional adjustment like switching from board teaching method to multimedia one and replacing item bank with class explanations. On the contrary, course exploration for this kind of course should get back to basics and explore how it can assist the students to synthesize their scattered spectroscopic knowledge into the ability to comprehend structures, scientific reasoning, and professionalism. Based on this perspective, the use of outcome-based education approach is a good guide for the intended learning outcomes, SPOC-blended learning can provide practical help regarding resources and instruction processes, while the adoption of values-based approach to design this course can provide educational assistance for the scientific ethics and social responsibilities. Through coordinated integration of all these aspects, the inherent issues of the reduction in-contact spectroscopic analysis course, namely, extensive knowledge, limited teaching time, high cognitive load, and unstable learning outcomes, can be solved effectively. As far as this spectroscopic analysis course with limited learning hours of approximately 32 h, what the best choice that this course can do is give up covering comprehensively, instead, choose a selective approach and emphasize on focused content, principle, interpretation reasoning, and alignment with the next learning stages. Specifically, it includes course content arrangement and optimization, adoption of problem and case driven teaching as the core of this instructional process, promotion of pre-class and post-class learning through SPOC platform, promotion of knowledge assimilation via classroom discussion and interpretation reasoning, enhancement of students' disciplinary knowledge through values-based education, and finally connection between this course and following lab classes in spiral way to make the learning more efficient.

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