

Article

Enhancing Teaching Effectiveness in Solar Thermal Utilization Technology Course through a BOPPPS-PBL Hybrid Model

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Abstract: The escalating global energy crisis has significantly accelerated the exploration and utilization of solar energy, rendering specialized academic courses indispensable for cultivating competent technical professionals in the renewable energy sector. However, conventional teaching models predominantly rely on passive knowledge transmission and frequently neglect the development of practical engineering skills, thereby limiting student competency. This study proposes and evaluates a hybrid pedagogical framework that integrates the BOPPPS model—comprising Bridge-in, Objective, Pre-assessment, Participatory learning, Post-assessment, and Summary—with project-based learning (PBL) to form a comprehensive BOPPPS-PBL teaching model. A quasi-experimental design was implemented wherein two cohorts of students enrolled in an identical solar thermal utilization technology course; one cohort experienced the hybrid BOPPPS-PBL model while the other followed the traditional instructional approach. Teaching effectiveness was systematically evaluated through student satisfaction questionnaires, final examination scores, and semi-structured teacher interviews. Results indicated that overall student satisfaction in the BOPPPS-PBL group reached 81%, approximately 30 percentage points higher than that of the traditional group. Furthermore, the average final examination score in the experimental group was nearly 15% higher, and the proportion of high-achieving students scoring 70 or above was 2.5 times greater. These improvements are attributed to enhanced teacher-student interaction and active learning engagement, which collectively promote both theoretical comprehension and practical skill acquisition. Teacher interviews further corroborated the model's effectiveness in increasing student engagement and instructor enthusiasm. The BOPPPS-PBL hybrid model thus provides a robust and replicable strategy for reforming energy-related engineering courses and offers valuable pedagogical insights applicable to broader engineering education contexts.

Keywords: boppps model; project-based learning; solar thermal energy; teaching reform; student engagement; engineering education

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1. Introduction

As the worldwide energy shortage and global warming driven by carbon emissions become increasingly severe, the development of renewable energy is urgent to reduce fossil fuel dependence. Among various renewable energy sources, solar energy stands out as a promising, inexhaustible, ubiquitous, high-capacity, and environmentally friendly resource [1]. For instance, the energy received by the Earth from the sun within just one hour is sufficient to fulfil the global energy demand for an entire year [2]. Solar energy can be converted into thermal energy, electrical energy, or solar fuels, and this conversion plays a significant role in supplementing energy supply and reducing carbon emissions. Beyond the conversion of solar energy into electricity through photovoltaic solar cells, solar thermal conversion is another key utilization method [3]. Currently, with the rapid development of solar thermal energy collection and conversion applications, the demand for relevant technical professionals in this field is increasing. Renewable energy generated approximately 9.8 million direct and indirect jobs worldwide by the end of 2016, and this

number is expected to exceed 24 million by 2030, highlighting the significant demand for human resources in the renewable energy sector [4]. The cultivation of highly skilled engineers is essential for the effective utilization of renewable solar energy. Higher education plays a critical role in cultivating technical professionals, enabling effective fulfillment of societal demands through systematic knowledge transfer and skill development.

At present, solar thermal utilization technology has been designated as a compulsory course in the New Energy Science and Engineering major in China. The course is designed to equip students with a comprehensive grasp of the fundamental theories, technologies, methods, and practical applications associated with solar thermal utilization. This course aims to cultivate students' ability to analyze and solve problems in this field, enhance their design capabilities and innovative thinking, and provide essential knowledge and technical support for their future careers in the energy sector. However, due to reliance on conventional lecture-based teaching models, several prominent challenges persist in the current practical teaching of this course in China, indicating the need for pedagogical innovation. For example, conventional lectures often adopt a one-way delivery model in which teachers disseminate content while students passively receive information, typically relying on rote memorization to acquire knowledge [5, 6]. Such an approach tends to make classroom teaching less engaging and interactive, leading to diminished student participation. Consequently, learning efficiency declines, and students' abilities in independent thinking and critical judgment remain underdeveloped. In addition, this teaching process often places excessive emphasis on theoretical knowledge while neglecting practical application, thereby failing to foster students' ability to apply what they have learned in real-world contexts. These challenges significantly hinder the development of highly technical professionals in the field of solar thermal utilization.

To improve teaching effectiveness, educators in relevant disciplines across China are actively exploring innovative teaching strategies. For instance, a blended teaching model combining online and offline approaches has been implemented for the solar thermal utilization technology course through the "Tsinghua Online" platform. The findings indicated that appropriately incorporating online learning can enhance students' autonomous learning ability and learning performance. Similarly, to address challenges in the teaching of the energy and power engineering major, a teaching model integrating the "MOOC" platform with face-to-face instruction has been proposed [7]. This model overcomes limitations of conventional instruction and improves students' application abilities. In the energy systems course, a project-based learning (PBL) teaching model centered on the overarching task of designing an efficient and low-carbon campus energy system has been developed. This model consists of subtasks organized across different stages, emphasizing multi-energy complementarity and cascade utilization, which helps students systematically master energy utilization and sustainable development principles. Additionally, the flipped classroom model has gained popularity in recent years as a means to further motivate students. In this approach, instructors construct knowledge frameworks, while students conduct topic-specific research and present relevant chapter content and theoretical principles in class [8, 9]. This approach promotes the development of self-directed learning abilities and communication skills. However, the aforementioned teaching approaches often fail to fully leverage teacher-student interaction, limiting learners' active participation throughout the learning process. Moreover, students frequently lack opportunities to apply the knowledge acquired in practice, thus restricting the development of their practical skills. Therefore, it is crucial to explore strategies for strengthening teacher-student interaction during the teaching process to enhance students' understanding of theoretical knowledge while simultaneously fostering their practical competencies.

In recent years, the BOPPPS teaching model, a teaching framework originally developed for teacher training in Canada, has been widely adopted in multiple countries and regions. The BOPPPS model is a student-centered instructional approach comprising six interconnected stages that form a complete pedagogical cycle [10]. It facilitates active

student participation in the classroom and enhances their sense of self-efficacy. This framework emphasizes active student engagement and real-time feedback, enabling instructors to make immediate instructional adjustments that improve teaching effectiveness [11]. By fostering interactive teacher-student collaboration, this model significantly strengthens professional knowledge acquisition and students' career competitiveness. At present, the BOPPPS method has been widely used in medical undergraduate teaching, clinical internships, and experimental teaching, effectively improving teaching outcomes [12-14]. For example, application of the BOPPPS model in lung cancer courses stimulated students' learning enthusiasm and increased their satisfaction with the course, thereby improving their exam scores and comprehensive abilities [15]. These studies demonstrate that the BOPPPS model has successfully enhanced students' academic knowledge. However, its application has rarely been explored in energy courses represented by solar thermal utilization technology. This study aims to fill this gap by systematically applying the BOPPPS model to the teaching of solar thermal utilization technology courses. Notably, the BOPPPS model primarily focuses on enhancing theoretical knowledge acquisition through efficient classroom teaching.

However, as an applied engineering course, solar thermal utilization technology requires both theoretical understanding and practical competency, the latter of which is often underemphasized in current teaching. To address this gap, this work integrates project-based learning into the BOPPPS model, enhancing students' ability to apply knowledge practically. The project-based learning approach is similarly recognized as an effective student-centered teaching approach that fosters applied skills [16]. Since the late 20th century, the project-based learning approach has been widely adopted in engineering education, promoting students' self-development and application of knowledge in practice. For example, in college-level probability and statistics courses, students taught with the project-based learning approach significantly outperformed those exposed to conventional instruction in assessments [17]. In the project-based learning model, instructors serve as facilitators while students apply theoretical knowledge to real-world projects, creating a theory-practice synergy that substantially enhances learning outcomes. This study on the BOPPPS-project-based learning hybrid teaching model is anticipated to provide valuable insights and references for the solar thermal utilization technology course as well as other energy-related and engineering courses.

2. Theoretical Frameworks

The BOPPPS model comprises six sequential stages: Bridge-in (B), Objective (O), Pre-assessment (P), Participatory learning (P), Post-assessment (P), and Summary (S). During the Bridge-in stage, instructors engage students using compelling content—such as evocative images or videos, thought-provoking questions, or reviews of prior knowledge. In the Objective stage, clear learning goals are articulated, along with their real-world relevance, to enhance motivation and purposeful learning. The Pre-assessment stage gauges foundational understanding through brief quizzes or targeted questions, enabling timely adjustments to instructional pacing and complexity. The Participatory learning stage constitutes the pedagogical core: instructors design interactive, learner-centered activities that integrate direct instruction with active student participation, supporting the development of self-regulated learning strategies. In the Post-assessment stage, learning outcomes are evaluated against stated objectives, and student feedback informs instructional effectiveness. Finally, the Summary stage reinforces central concepts, encourages metacognitive reflection, and outlines follow-up tasks. Each instructional unit adheres to this six-stage structure, with individual stages typically lasting 5–15 minutes to maintain focused attention on specific learning goals [18]. Instructors retain flexibility to adapt the sequence and duration of stages according to pedagogical needs.

Problem-Based Learning (PBL) is an instructional approach centered on self-directed learning within authentic, project-based contexts, where students assume increasing responsibility for their learning process. It represents a shift from traditional transmission-

oriented models, fostering deeper engagement through inquiry, challenge, and application [19]. PBL draws theoretical grounding from cognitive and social constructivist perspectives. Cognitive constructivism emphasizes how learners build understanding through personal experience, privileging hands-on experimentation and inquiry-driven exploration [16]. Social constructivism highlights the role of dialogue, collaboration, and shared meaning-making in knowledge development, underscoring the significance of peer interaction and community in learning [20]. Within this study, cognitive constructivism informs experiential learning activities, while social constructivism supports collaborative peer engagement—both critical for conceptual clarity and skill acquisition in engineering education. Implementation involves students collaboratively selecting project topics, co-developing implementation plans, executing projects through sustained teamwork, and jointly evaluating outcomes. Following theoretical instruction delivered via the BOPPPS model, instructors scaffold students through structured PBL experiences to deepen comprehension and strengthen practical application [21]. This integrated approach cultivates applied competencies, may alleviate academic pressure, and systematically develops teamwork and communication abilities.

3. Research Methodology

3.1. Participants

The study involved students enrolled in the solar thermal utilization technology course from two consecutive cohorts of the New Energy Science and Engineering major. The 2024 cohort ($n = 39$) received instruction via the traditional teaching model and constituted the control group, while the 2025 cohort ($n = 36$) was taught using the BOPPPS-PBL hybrid model and formed the experimental group. Both groups covered identical course content, with the sole variation being the pedagogical approach. Course instructors were interviewed to gather qualitative insights on implementation experiences and perceived efficacy. Student satisfaction was measured through standardized questionnaires, and final examination scores served as the primary quantitative indicator of learning outcomes.

3.2. Implementation of the Boppps-pbl Hybrid Model

3.2.1. Boppps Model

In the traditional teaching model, teachers often use PowerPoint presentations for one-way information delivery. In contrast, the BOPPPS-PBL hybrid model adopts a student-centered approach, which enhances student participation and understanding of theoretical concepts. Moreover, it helps students develop application skills, self-directed learning, teamwork, and other comprehensive competencies. The Bridge-in stage introduces the lesson background, the origins of certain theories or principles, and a review of relevant content from previous lessons. For example, at the beginning of the Solar Thermal Power Generation unit, a short video of the Delingha Tower Solar Thermal Power Station in Qinghai Province is shown to provide students with a vivid impression of the technology. Following the video, the teacher poses the question: What are the components of a thermal power generation system? This prompts students to engage with the lesson while keeping the question in mind. Additionally, since solar thermal power generation systems involve thermal energy storage, this stage can include a brief review of previously covered knowledge on thermal storage. This lays the foundation for the current lesson's learning objectives.

In the Objective stage, teachers clarify the key focus of the lesson, along with the knowledge and skill goals to be achieved. This involves introducing the main theoretical concepts and practical applications, while highlighting the teaching key points and difficulties. This enables students to understand the value and direction of the lesson, thereby enhancing their learning efficiency and motivation. For example, in the chapter on calculating angles related to solar radiation, the key content includes definitions of different angles, the relationships among them, and the corresponding calculation formulas. This knowledge supports subsequent calculations of solar radiation parameters.

In the Pre-assessment stage, teachers design a small set of simple questions based on either the previous lesson or the preview materials for the current lesson. By randomly selecting students to answer these questions, teachers can gauge students' prior knowledge and initial understanding of the new topic. Additionally, teachers can use the "Xuexitong" platform to release several simple multiple-choice or polling questions related to the lesson. The quick responses collected provide insight into students' baseline knowledge, enabling teachers to adjust the pace and emphasis of the upcoming instruction. For example, at the beginning of the solar thermal energy storage lesson, teachers may ask whether students are aware of the different forms of thermal storage and the types of storage media involved, to evaluate their existing knowledge on this topic.

As the core component of the BOPPPS teaching model, participatory learning emphasizes a student-centered approach. In this stage, teachers flexibly employ diverse teaching resources to promote interactive learning and actively engage students in the learning process. For instance, when teaching calculations related to solar radiation angles, the teacher first explains the fundamental definitions and relevant formulas. Then, for special solar positions (such as declination angles during equinoxes and solstices), students are guided to apply their understanding to solve problems. Following collaborative group work on sample problems, selected representatives present their solutions on the board to reinforce comprehension and application of formulas. Subsequently, building upon the concepts of solar altitude and solar hour angles, the lesson expands to include calculations of sunshine duration and sunrise/sunset times. Students compare their computed results with official meteorological data, thus experiencing the application of theoretical knowledge in real-world contexts. The instructor then guides students to analyze any discrepancies between their calculations and the official data, fostering critical thinking skills. This phase not only emphasizes teacher-student interaction but also develops students' self-directed learning and problem-solving abilities.

In the Post-assessment stage, teachers focus on the challenging theoretical concepts introduced during the lesson as key elements of evaluation. This post-test serves to assess students' understanding of the instructional content, allowing teachers to refine subsequent teaching plans and implement targeted improvements. Calculations involving solar declination, altitude, and incidence angle, for instance, represent core competencies that should be evaluated through a variety of problem-solving exercises.

In the Summary stage, the teacher guides students to summarize the lesson's key content using flowcharts, while reiterating the focal points and challenging concepts. To extend learning beyond the classroom, thought-provoking questions are posed to stimulate further exploration. Additionally, the teacher provides opportunities for student reflection. Finally, the teacher assigns relevant homework to reinforce the lesson's objectives and promote continued practice.

3.2.2. PBL Model

The solar thermal utilization technology course is a highly practical engineering subject where hands-on training is essential for students to integrate theoretical knowledge with practical skills. The problem-based learning (PBL) approach serves as an important complement to classroom instruction. After students have acquired fundamental concepts, calculation methods, and knowledge of system components, the implementation of the PBL model through course design projects further strengthens their applied technical capabilities. For example, the design of solar water heating systems represents a key application of the course content. Accordingly, instructors can develop various design topics based on regional conditions and real-world application scenarios for hot water systems. Students are organized into groups of three to four members, with each group selecting one topic for development. Each group plans its timeline and assigns responsibilities. Applying theoretical knowledge, students initially screen appropriate system configurations and select suitable equipment, then calculate system capacity and equipment dimensions. Through collaboration and research, each group finalizes the

design scheme for the entire water heating system, produces design drawings, and writes a technical report. Finally, students deliver a 5–7 minute group presentation to the entire class. The instructor provides feedback and assigns a grade, which is shared equally among all group members.

3.3. Assessment of Teaching Effectiveness

The effectiveness of the traditional teaching model and the new BOPPPS-PBL hybrid model was evaluated using questionnaire surveys, final score analysis, and teacher interviews. At the conclusion of the course, a brief satisfaction survey was administered to all students. The questionnaire employed a five-point Likert scale (1 = lowest rating, 5 = highest rating) to assess perceptions of classroom participation, knowledge acquisition, skill development, and overall teaching quality. The five response options were labeled as "lowest rating", "lower rating", "moderate rating", "higher rating", and "highest rating", corresponding to integer scores from 1 to 5. All students in both groups completed the survey independently based on their learning experience. To quantitatively compare learning outcomes between the two groups, final scores were systematically analyzed. Final scores comprised regular assessment scores and examination scores, each contributing 50% to the total. Results were reported as mean $\pm$ standard deviation. Statistical analysis was performed using Origin software, and intergroup differences were assessed using an independent-samples t-test; a p-value < 0.05 was interpreted as statistically significant. Additionally, the distribution of students across four performance bands (≥ 80 , 70–79, 60–69, and < 60) was compared between groups. To gather instructor perspectives on the implementation of the new teaching model, semi-structured interviews were conducted with four faculty members who delivered the course. These instructors were aged between 30 and 40 years. Each interview lasted approximately 30 minutes and focused on observed student engagement patterns, personal teaching experiences, and reflections on the instructional design. The interviews provided comprehensive insights into faculty evaluations of the BOPPPS-based teaching approach.

4. Results and Discussion

This section analyzes and discusses the evaluation of the teaching process in the two models, drawing on student questionnaire responses, final examination scores, and teacher interviews. Student questionnaires measured course satisfaction, final scores reflected learning outcomes, and teacher interviews captured professional perceptions of the teaching model.

4.1. Questionnaire Survey Analysis

Students in both teaching models evaluated the teaching process from four aspects based on their personal learning experiences. Their feedback is summarized in Table 1 and 2. Compared with the traditional teaching group, students in the BOPPPS-PBL group show higher satisfaction in terms of classroom participation, knowledge acquisition, skill improvement, and comprehensive teaching evaluation. The majority of their responses fell within the "satisfied" or "very satisfied" range, indicating superior teaching effectiveness of the BOPPPS-PBL model.

Table 1. Responses from Students in the Traditional Teaching Model Group on Different Items in the Questionnaire.

Items	Distribution of student responses				
	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Classroom participation	10.3%	35.9%	33.3%	12.8%	7.7%
Knowledge acquisition	17.9%	38.5%	28.2%	10.3%	5.1%

Skill improvement	7.7%	30.8%	25.6%	25.6%	10.3%
Comprehensive teaching evaluation	12.8%	38.5%	30.8%	12.8%	5.1%

For clearer comparison, the proportion of satisfaction (the sum of "satisfied" and "very satisfied") for each item is displayed in Figure 1, while the corresponding mean evaluation scores for both groups are presented in Figure 2. The BOPPPS-PBL group achieved a satisfaction rate of 81% for the overall teaching evaluation, which is approximately 30% higher than that of the traditional group (Figure 1). In particular, in terms of classroom participation and skill improvement, the BOPPPS-PBL group showed a remarkable increase compared to the traditional group. These findings are further corroborated by the significantly higher mean scores and the statistically significant differences ($p < 0.001$) shown in Figure 2. This improvement in teaching effectiveness can be attributed to two main features of the BOPPPS-PBL model. On one hand, the BOPPPS-PBL model highlights teacher-student interaction throughout the teaching process. This approach actively engages students in discussions, critical thinking, presentations, and testing, thereby significantly enhancing students' learning engagement. On the other hand, this model incorporates practical training for curriculum design, which cultivates students' application skills, self-directed learning abilities, and teamwork competence. Moreover, by emphasizing the integration of multidisciplinary knowledge, the PBL process enhances students' ability to synthesize information across disciplines. As for the aspect of knowledge acquisition, the difference in satisfaction between the two groups is relatively smaller compared with other items. This may be because students rely on rote memorization to acquire theoretical knowledge in the traditional model, and it seems to have certain effects. Nevertheless, this approach lacks systematic training for applying acquired knowledge to practical contexts, which ultimately limits the development of students' comprehensive competencies (As shown in Table 2).

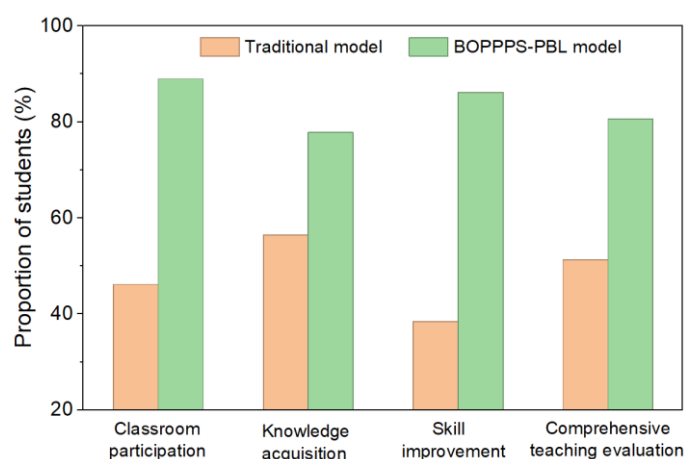


Figure 1. Comparison of the Sum of the Proportions of Students Who Chose "Very Satisfied" and "Satisfied" for Different Survey Items in the Two Groups.

Table 2. Responses from Students in the Boppps-pbl Teaching Model Group on Different Items in the Questionnaire.

Items	Distribution of student responses				
	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Classroom participation	33.3%	55.6%	11.1%	0.0%	0.0%

Knowledge acquisition	38.9%	38.9%	19.4%	2.8%	0.0%
Skill improvement	36.1%	50.0%	13.9%	0.0%	0.0%
Comprehensive teaching evaluation	33.3%	47.2%	16.7%	2.8%	0.0%

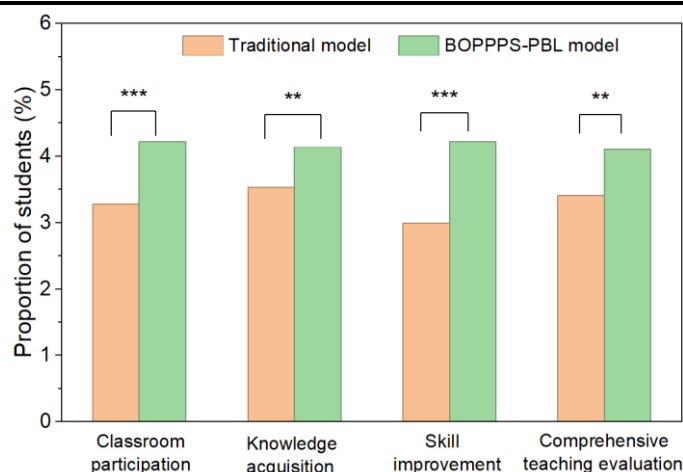


Figure 2. Scores of Course Effectiveness and Satisfaction between the Two Groups (** Denotes $P < 0.01$, *** Denotes $P < 0.001$).

4.2. Score Analysis

Guided by the educational philosophy of student-centeredness, the BOPPPS-PBL teaching model was implemented in the solar thermal utilization technology course. Table 3 presents the average final scores for the two student groups. Characterized by active teacher-student interaction and the integration of theoretical learning with practical training, the BOPPPS-PBL model significantly enhanced academic performance relative to the traditional lecture-based approach. As shown in Table 3, the BOPPPS-PBL group attained a markedly higher mean final score (mean = 71.8) compared to the traditional group (mean = 62.7), reflecting an approximate 15% improvement. The statistical significance of this difference ($p < 0.001$), illustrated in Figure 3a, further substantiates the effectiveness of the BOPPPS-PBL model. Moreover, within the BOPPPS-PBL group, the proportions of students scoring 70–79 and ≥ 80 points were 44% and 22%, respectively, whereas the corresponding figures for the traditional group were only 21% and 3% (Figure 3b). Combining the 70–79 and ≥ 80 categories indicates that the proportion of high scorers in the BOPPPS-PBL group was 2.8 times that of the traditional group. In contrast, only 8% of students in the BOPPPS-PBL group scored below 60, compared to 33% in the traditional group. These results clearly demonstrate that the BOPPPS-PBL model increases both the proportion of high achievers and the overall pass rate. Notably, the average regular score in the BOPPPS-PBL group was only 3% higher than that of the traditional group, indicating a relatively narrow gap. The regular score constitutes one component of the final score and comprises group project scores as well as independently completed after-class assignments, the latter of which are ungrouped and unsupervised. A plausible explanation for the modest difference in regular scores is that these routine tasks afforded greater opportunities for open collaboration and discussion. Consequently, less proactive students may have relied on peers or sought online assistance, thereby obscuring genuine differences in individual learning ability. Furthermore, the limited teacher-student interaction inherent in the traditional model often fails to ensure full student engagement and lacks robust mechanisms for assessing individual performance. By contrast, the BOPPPS-PBL model effectively establishes a student-centered framework that substantially expands participation opportunities, thereby enhancing learning motivation and outcomes and yielding superior academic performance.

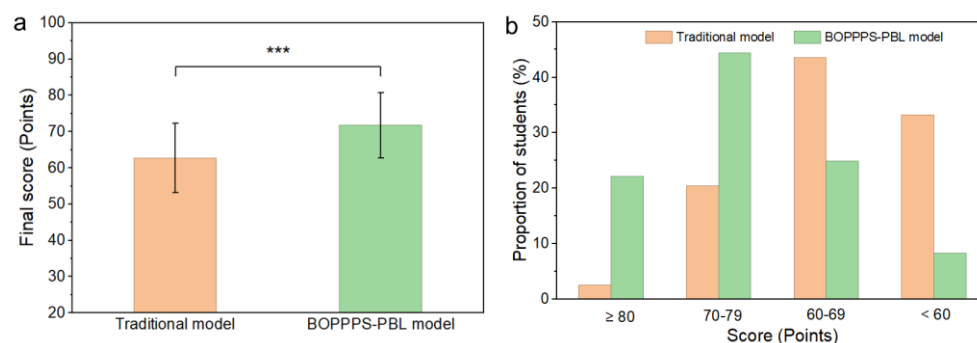


Figure 3. (A) Comparison of the Average Scores of Students in the Two Groups (***) Denotes $P < 0.001$. (B) Distribution of Final Scores of Students in the Two Groups.

Table 3. The Average Final Scores of Students under the Two Models.

Model	Mean	Standard deviation
Traditional model	62.7	9.6
BOPPPS-PBL model	71.8	9.0

4.3. Interview Analysis

To assess the effectiveness of the BOPPPS-PBL teaching model from teachers' perspectives, interviews were conducted with instructors of the relevant courses. These interviews gathered feedback on multiple dimensions of the new teaching model, including students' attentiveness (i.e., head-up rate), responsiveness to questions, collaborative behavior, instructors' teaching enthusiasm, lesson preparation experience, classroom delivery fluency, and overall evaluation of the model. Responses were systematically analyzed to synthesize teacher perspectives. For example, one instructor observed that under the BOPPPS-PBL model, students significantly reduced mobile phone usage during class, followed the lecture pace more closely, and responded promptly to questions. Several instructors also noted that this approach mitigated the frustration commonly experienced in traditional one-way instruction when students provided little or no feedback. Alongside these positive observations, some instructors raised practical challenges: one remarked that achieving smooth classroom delivery required substantially more time for lesson preparation—particularly in designing distinct instructional stages—and greater effort to ensure content remained current and pedagogically engaging.

Overall, interview findings indicate that the BOPPPS-PBL model offers notable advantages over conventional instruction. As a structured hybrid framework, it strengthens classroom organization and supports systematic sequencing of teaching content. Instructors reported a more vibrant and interactive learning environment, marked by heightened student enthusiasm and participation. This enhanced engagement contributed to greater instructor satisfaction and professional motivation. Specifically, interactive activities—including group discussions, result presentations, and collaborative course design—stimulated student interest, deepened involvement, and strengthened analytical and problem-solving competencies. Strategic integration of multimedia resources further enriched both content delivery and methodological diversity. The model also significantly improved teacher–student interaction, encouraging more frequent and substantive student contributions to classroom discourse and inquiry. Such sustained engagement not only increased the pedagogical appeal of lessons but also reinforced knowledge comprehension and long-term retention. Crucially, the BOPPPS-PBL model facilitates a shift from passive reception to active knowledge construction, promoting deeper conceptual understanding and more robust application capabilities.

Traditional instruction remains largely teacher-centered. The course on solar thermal utilization technology involves abstract theoretical concepts and applied calculations

closely tied to real-world engineering contexts, often leading to student disengagement, diminished motivation, and suboptimal learning outcomes. Consequently, enhancing learner interest, improving instructional efficacy, and refining pedagogical strategies remain persistent priorities. The BOPPPS-PBL hybrid model addresses these challenges by integrating foundational theory with authentic, practice-oriented design tasks within a student-centered paradigm. This approach yields clear benefits over conventional methods—particularly in stimulating intrinsic motivation, sustaining attention, and optimizing learning efficiency. By emphasizing active participation and intellectual initiative, the model accelerates students' transition toward self-directed learning while cultivating advanced problem-solving capacities and critical thinking skills.

5. Limitations and Future Directions

This study demonstrated that the BOPPPS-PBL teaching model effectively enhances teaching outcomes in the solar thermal utilization technology course, including improvements in both knowledge acquisition and skill development. However, several limitations require further refinement in future research. Firstly, the comparison between the two teaching models employed a sequential experimental design, which offers slightly lower internal validity than a parallel design—such as dividing a class into two groups for simultaneous intervention and control. This approach was adopted due to the relatively small current enrollment in the course, making a parallel design impractical. As student numbers increase, a parallel design will be implemented to strengthen validation of the model's effectiveness -. Secondly, variables such as academic year and gender may influence learning outcomes, introducing complexity into result interpretation [22]. Future applications should therefore extend across diverse grade levels and class types to mitigate such confounding effects. Thirdly, student feedback responses vary considerably across disciplines and learning contexts. Subsequent research should systematically examine how disciplinary characteristics and environmental factors—including class size and classroom atmosphere—shape students' perceptions of feedback. Although the sample size of 36–39 students satisfies minimum statistical requirements, it remains modest; larger-scale studies are needed to robustly confirm the model's impact on teaching quality and skill development. Fourthly, the practical skills component of the curriculum was confined to a single knowledge domain. Future iterations should integrate themes spanning multiple domains across the full curriculum to foster more comprehensive and multifaceted skill development. Finally, the course instructor also served as the model's designer—a factor potentially enhancing instructional engagement during implementation. To better assess generalizability and objectivity, future replication should involve instructors unaffiliated with the model's original development.

6. Conclusion

This study proposed and implemented a novel BOPPPS-PBL teaching model in the solar thermal utilization course to enhance students' knowledge and skills. The BOPPPS component supports effective classroom pacing and stimulates student engagement and interest, while the PBL component reinforces knowledge application through project design and strengthens practical competencies. Student satisfaction with the BOPPPS-PBL model reached 81%, approximately 30 percentage points higher than under the traditional approach. The average final score in the BOPPPS-PBL group was 71.8—nearly 15% higher than that of the traditional group. Notably, the proportion of students scoring 70 or above in the BOPPPS-PBL group was 2.5 times greater than in the traditional group, indicating marked improvement in academic outcomes. Teacher interviews indicated that the model supports structured instructional delivery, enhances student motivation and learning efficiency, and contributes positively to instructor engagement. Overall, compared with the traditional teaching model, the BOPPPS-PBL approach strengthens teacher–student interaction, increases structural clarity and methodological diversity in instruction, and clarifies learning objectives. It effectively fosters student interest and motivation while

supporting integrated development of knowledge and skills. Furthermore, this work offers a conceptual and methodological basis for curriculum innovation in related energy education contexts.

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Competing Interests: No potential conflict of interest was reported by the authors.

Data Availability: The datasets generated and/or analyzed during the current study are available from the corresponding author upon request.

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