

INTEGRATING SENSE LAB AND PROJECT-BASED LEARNING IN LIGHTING DESIGN EDUCATION

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ABSTRACT

Traditional lighting design courses rely solely on classroom lectures, leaving students unable to experience and perceive light in real-world contexts. This research focuses on "Integrating Specialized Lighting Teaching Facilities with Project-Based Learning (PBL)" as a teaching practice study, elevating the "Lighting Design" course to a design practice-oriented curriculum. The course structure simulates the various stages of the lighting design process and incorporates the PBL methodology grounded in the CDIO framework. CDIO represents "Conceive," referring to the analysis of current needs and encouraging students to employ divergent thinking to address challenges; "Design," where students conceptualize solutions from a user-centric perspective; "Implement," involving the transformation of solutions or designs into prototypes, encompassing solution validation and production; and "Operate," focusing on continuous adjustments and testing to refine outcomes or projects based on real-world application. The CDIO framework helps train students to solve real-world lighting design problems.

The course also uses Feng Chia University's "Sense Lab" as a teaching field, where students utilize adjustable lighting systems and equipment to learn specialized lighting terminology and experience diverse lighting scenarios. In the PBL segment, students develop "light boxes" and "lighting design projects" as assessment tools to demonstrate learning outcomes. The course fosters integrated learning through case discussions, DIALux EVO lighting simulation software, and final project presentations. This innovative curriculum addresses the traditional emphasis on theoretical instruction in lighting design courses, enhancing hands-on experiential learning. Feedback collected through end-of-term surveys indicates significant improvements in students' understanding and application of lighting design, aligning with the project's anticipated goals.

KEYWORDS

Project-based learning (PBL), lighting design, Sense Lab, action research, Standards: 2,5,6,7,8

INTRODUCTION

"Lighting design" is an essential foundational knowledge in architecture and interior design. The course aims to equip students to effectively utilize light in spaces to fulfill functional and aesthetic requirements. To achieve this, students must possess a solid understanding of optical and physical principles and an appreciation for spatial design aesthetics, enabling them to excel in lighting design.

However, traditional lighting design courses often focus primarily on theoretical content, covering basic optical concepts, characteristics of light sources and fixtures, lighting methods, illuminance calculations, and spatial lighting case studies. Due to limited teaching resources and facilities, most courses rely on diagram-based explanations, leaving students with minimal opportunities to experience light in real spatial contexts or engage in hands-on lighting design projects. This theory-centric teaching model restricts students' ability to apply their knowledge in practical design and implementation.

Lighting design should not remain confined to traditional lectures, nor should its outcomes be limited to visually appealing renderings. This study advocates for integrating theoretical knowledge with practical application to enhance the teaching effectiveness of lighting design courses. This approach aims to enable students to comprehensively understand the application of light, acquire the expertise to evaluate the simulation effects of lighting designs, and professionally assess the quality of luminous environments.

How can "Lighting Design" transition from a purely theoretical course to one oriented toward practical application in design? Achieving this requires students to actively explore and investigate problems and engage in deep critical thinking throughout the learning process. Scholars have noted that incorporating "Design Thinking" and "Problem-Based Learning (PBL)" into cornerstone courses can enhance and sustain students' interest in engineering, motivate them for advanced coursework, increase hands-on experience, and improve their performance in integrated design courses. This approach addresses the gap between theory and practice in engineering education, enabling students to develop higher-order skills such as applying knowledge, analysis, synthesis, and evaluation (Dym et al., 2005).

In collaboration with TU Delft, Feng Chia University established the first subtropical "Sense Lab," an innovative teaching and research facility focused on environmental comfort and human perception, encompassing light, airflow, acoustics, and psychological well-being (Figure 8). The "Experience Room" on the first floor of the Sense Lab features lighting that



Figure 9. Sense Lab: Control and Experiential Exploration of Lighting

allows precise control of various lighting conditions. All fixtures' luminance and color temperature can be independently adjusted using dedicated dimming software, facilitating experiments and experiential learning. Additionally, the basement's small-scale "Light Chamber" is equipped with LED panel lights, linear strip lights, and spotlights, enabling the creation of various lighting scenarios. This setup supports various educational and research purposes, integrating furniture arrangements and relevant instrumentation.

By integrating the Sense Lab into the lighting design curriculum, students gain hands-on experience in controlling and experiencing diverse lighting scenarios, significantly enhancing their understanding of lighting principles and their practical application. This study aims to leverage the Sense Lab as a teaching environment, incorporating CDIO and PBL into project-based coursework. The CDIO 'Integrated Learning' model allows students to engage with multiple small projects, progressing from basic to advanced levels. This approach fosters critical decision-making skills, enhances student interest, and improves learning outcomes. Practical projects, combined with the Sense Lab as the lighting teaching environment, enable students to develop their knowledge, operation, and evaluation of light effectively.

METHODOLOGY

CDIO

The CDIO engineering education design concept was co-founded by the Massachusetts Institute of Technology (MIT) in collaboration with Chalmers University of Technology, Linköping University, and the Royal Institute of Technology in Sweden. It is a novel educational framework based on the product lifecycle process to comprehensively enhance students' foundational competencies (Crawley, 2014). This framework promotes holistic development in foundational knowledge, personal skills, teamwork, communication, and systems thinking. Particularly in engineering systems capabilities, it emphasizes using knowledge to create value for society through innovative processes of conceiving, designing, implementing, and operating within corporate, societal, and environmental contexts. The core definition and principles of CDIO are summarized as follows (Crawley, 2007):

- **Conceive:** Analyze problems and define needs based on understanding societal and market demands, then propose conceptual designs for solutions.
- **Design:** Developing detailed technical and design specifications based on the conceived solution, integrating innovative elements into the concrete design.
- **Implement:** Transforming the design into practice, including manufacturing, testing, and refining prototypes.
- **Operate:** Deploy the designed system in real-world settings and continuously monitor and improve its performance and impact.

The primary goal of the CDIO framework is to cultivate students' ability to apply knowledge in real-world contexts. This prepares them to excel in diverse engineering and societal challenges and contribute to corporate and social development within a globalized context.

The 6th standard of CDIO emphasizes the importance of the engineering laboratory. The successful implementation of CDIO requires an academic environment that provides appropriate workspace, facilities, and tools, collectively known as the engineering laboratory. These spaces must support the entire project process—conceiving, designing, implementing, and operating—across simple and complex individual and group projects. In parallel, relevant infrastructure is developed to promote an active, hands-on learning approach. The

laboratories play a key role in demonstrating the significance of the environment to students and enhancing their education. The engineering laboratory serves as a crucial space where students can engage in creative and practical learning experiences. Moreover, the laboratory is an integrative, practical venue that supports the entire curriculum planning, distinguishing it from traditional labs (Guo et al., 2012) .

Problem-based learning (PBL)

Problem-Based Learning (PBL) was first introduced by McMaster University in Canada as a teaching and learning method centered on solving real-world problems. Project-Based Learning (PBL) builds upon the principles of inquiry-based learning, enabling students to construct their knowledge systems through the investigation and research of problem-solving projects, which they can then apply in real-world scenarios. Project-Based Learning consists of four key elements: content, activities, context, and outcomes. Content is derived from real-life problems characterized as complex, unpredictable, and interdisciplinary knowledge. Activities primarily refer to students' problem-solving actions. Context refers to the environment that supports students in conducting exploratory learning. Outcomes are the knowledge or skills students acquire during or at the end of the learning process, such as collaborative learning skills, life skills, and self-management abilities (Zhai et al., 2018).

Problem-Based Learning (PBL) is characterized by several key features (Chen, 2012). It focuses on problem-centered learning, where students collaboratively collect, analyze, and discuss information to solve problems. The group-based learning model fosters effective problem-solving through interaction and shared experiences. Discussions are central to the process, encouraging critical analysis and development of solutions. PBL emphasizes active learning, requiring students to set objectives, assess their abilities, and engage in self-evaluation. Teachers act as facilitators, guiding discussions and providing feedback to enhance problem-solving and critical thinking.

PBL is designed based on practical and theoretical needs to motivate learners, guiding them to understand, apply, and create knowledge. Additionally, learners can construct or interpret information through experiential learning, case studies, or knowledge sharing (Tiong, 2004). PBL emphasizes critical thinking, learning how to learn, and collaborating with others. These processes empower students to become autonomous, skilled, and self-discovering, enhancing teamwork skills and spirit. Due to these characteristics, PBL is widely applicable across various student groups and disciplines (Valdez et al., 2009).

TEACHING PLANNING

The course objectives of "Lighting Design" include defining and describing the basic knowledge of optics and identifying various types of lighting sources and lighting systems as the basis for lighting design. Be able to recognize, analyze, and appreciate the aesthetics of spatial lighting design and translate this into personal ideas about lighting design; apply lighting design principles; use appropriate lighting techniques for different types of spaces; and sum up ideal solutions.

The teaching theme is combined with the teaching concept of CDIO to transform PBL-oriented learning further. CDIO stands for "conceive," which refers to the analysis of current needs and encourages students to use divergent thinking to try to solve the challenges and problems they face; "design," which means that students must use the perspective of the demander to conduct Design is the process of outlining a solution; "implementation" refers to the process

of students converting a plan or design into a "prototype," including plan confirmation and production, which means the presentation of the design; "operation" refers to students The team or designer achieves satisfactory results or works based on the experience presented, through continuous revision and testing.

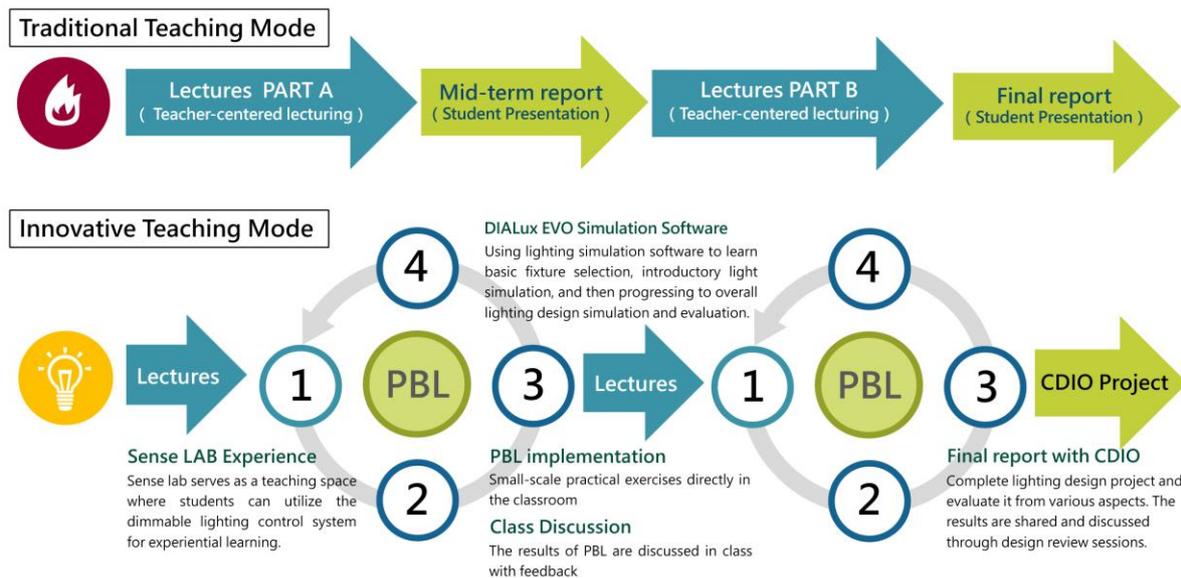


Figure 2. The difference between the innovative teaching mode and the traditional teaching mode of the "Lighting Design" course

This study compares classroom teaching units with various stages of the lighting design process and introduces CDIO course-specific practices to enhance student learning outcomes. PBL will be implemented as a teaching unit for several small, "design-oriented topics." Throughout the learning and operational phases at each stage, students will observe the progression of each lighting design process and simultaneously acquire the necessary knowledge and skills for each design stage. These professional skills will be applied to address complex lighting design projects (Figure 2). Students will also learn how to use different materials and lighting in the lighting control system of the Sense Lab, gaining hands-on experience in controlling and understanding light.

The research is organized into three stages: pre-teaching preparation, classroom teaching, and effectiveness evaluation, as illustrated in Figure 3. The "action research method" in this course uses questionnaires, scales, and student work as data collection tools. Quantitative data are analyzed using statistical methods, while qualitative data, such as feedback on changes in learning motivation, self-learning attitudes, and course acquisition, are gathered through unit feedback questionnaires. These qualitative responses serve as the primary data for the study. Over the semester, teaching follows the unit schedule, incorporating field teaching and special projects into the curriculum. Mid-semester formative assessments are conducted, and a post-questionnaire is administered at the end of the semester to allow students to self-assess their learning performance and outcomes. Special reports are evaluated using a rubric rating scale. Finally, all course materials and questionnaire results are subjected to statistical analysis.

A "direct assessment" method evaluates student project achievements, utilizing Rubrics for scoring. The "indirect assessment" method involves pre-test and post-test evaluations, with questions designed based on the course's core competencies. The questionnaire also

examines whether the teaching environment supports learning across various lighting topics. Additional reference assessment methods include tools such as the "midterm formative assessment" and "summative assessment" within Feng Chia University's iLearn 2.0 system.

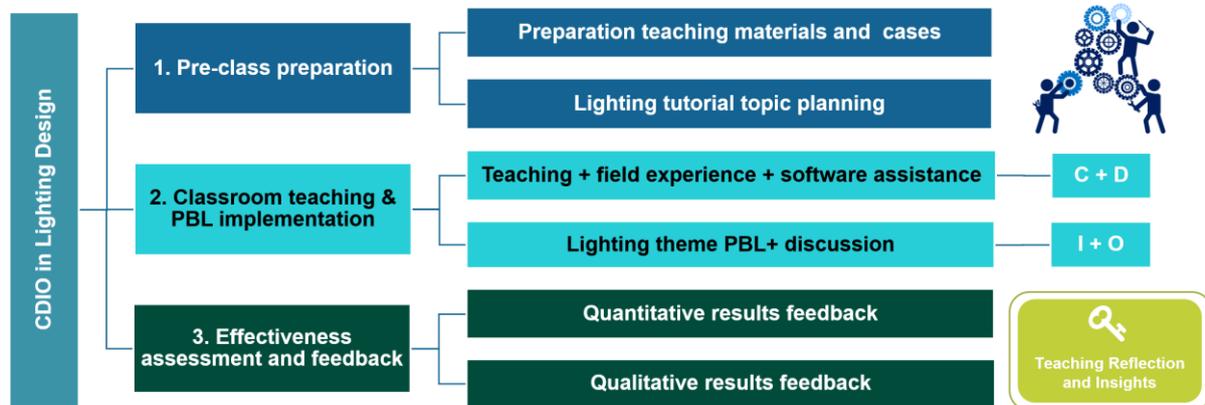


Figure 3. Three-stage research method

TEACHING IMPLEMENTATION

The subjects of this study were third-year students of the Interior Design Program of the School of Architecture. The data collected were the question-and-answer records, questionnaires, and homework in class. The class and research location were the "Experience Room" (1F) of the Sense Lab of the School of Architecture. And "Light chamber (B1)". The "Lighting Design" course scope can be divided into several central units, including "Lighting Principles and Visual Perception," "Light and Space Composition," "Lighting Environment and Psychology," "Light Sources and Lighting Forms," and "Lighting Simulation and Evaluation." The main teaching methods include classroom lectures, PBL topics, and lighting field teaching.

Classroom teaching

Through lectures, students were systematically introduced to the fundamental principles of optics, evaluation methods, and instrument operation techniques. In the classroom, students were encouraged to engage in critical thinking, ask questions, and receive timely supplemental explanations to enhance their understanding of the course content. Teaching strategies and resources such as Kahoot, Slido, and other Interactive Response Systems (IRS) were utilized to foster direct student interaction, allowing immediate feedback and active participation through questioning. These methods contributed to a more dynamic and engaging learning environment.

Lighting field teaching

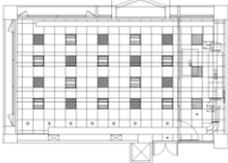
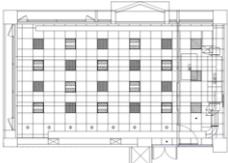
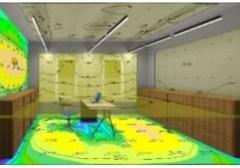
The course uses the Sense Lab's "Experience Room" as the classroom and uses the lighting control system to explain lighting design techniques. It also provides a "Light chamber" for students to operate light in practice and complete the projects.

Project-Based Learning

The course is designed as teaching modules incorporating PBL, requiring the application of the CDIO process to complete projects. It integrates the college's Sense Lab as a teaching platform into a structured teaching design spanning five progressive stages (Table 1).

Unit 1 covers professional lighting terminology and field lighting quality assessment. Students learn the definitions of terms and lighting environment standards, and they use optical instruments to evaluate the lighting quality of the Sense Lab, followed by group discussions and presentations. Unit 2 involves a "Light Box Experiment" where students select a "light & atmosphere" theme and design a 30cm cardboard box. They arrange the box's interior using various openings, shapes, colors, and materials, then use Sense Lab light sources to create lighting scenarios, then discuss the resulting lighting effects and shadows.

Table 3. Course Schedule and Instructional Design

PBL	CDIO	Field of use	Course Content	
【 Unit 1 】 Lighting Design principles	C			<ul style="list-style-type: none"> • Teach lighting design principles and the use of instruments • Introduce Sense Lab
【Unit 2】 Lightbox experiment	CDI			<ul style="list-style-type: none"> • Practice light and shadow in scaled spaces • Use Sense Lab lighting to assist in lightbox photography
【Unit 3】 Lighting control and experience	CD			<ul style="list-style-type: none"> • Utilize the Sense Lab lighting control system • Experience firsthand how changes in lighting affect perception
【Unit 4】 Lighting scenario	CDI			<ul style="list-style-type: none"> • Utilize luminaires and furniture to achieve lighting scenario design • Use the Sense Lab lighting control system
【Unit 5】 Lighting Design and Simulation	CDIO			<ul style="list-style-type: none"> • Use simulation software DIALux to complete the lighting design project • Use Sense Lab for assistance

Units 3 and 4 use the Sense Lab lighting control system, allowing students to familiarize themselves with lighting fixtures and control the light to experience the changes in lighting. Students then challenge each other with tasks to adjust the lighting to the required scenarios. Unit 5 is the final review, where students learn to use DIALux EVO lighting software with assistance from the Sense Lab environment. They then design residential lighting using DIALux and present their results for discussion.

ANALYSIS OF TEACHING OUTCOMES

Course Objective Achievement Status

Feedback from classroom interactions and surveys indicates that students widely acknowledge Sense Lab as an effective platform for lighting education. The project-based learning approach within Sense Lab has notably enhanced their understanding of lighting design. Table 2 presents the alignment between course objectives and core competencies, integrating teacher self-evaluation and student feedback. According to student responses, the teaching effectiveness closely matched the course objectives outlined in the syllabus, with evaluation scores ranging from 4.50 to 4.75(5 being the best).

Table 2. Achievement of the objectives of this course

Course Objectives	Course objectives achieved (teacher self-evaluation)					Student Feedback
	Very Easy	Easy	Medium	Hard	Very Hard	
1. Be able to define basic lighting knowledge as the basis for lighting design		V				4.75
2. Be able to recognize, analyze, and appreciate the spatial aesthetics of lighting design, and be able to develop personal lighting design ideas			V			4.50
3. Be able to apply lighting design principles and summarize ideal lighting design solutions			V			4.75

Student Learning Feedback

Student learning feedback was collected through a questionnaire, where students self-assessed their learning outcomes for each of the PBL units (Unit 1 to Unit 5) on a scale of 1 to 5 (with 5 being the best). The results showed that the highest rating was for Unit 3, focusing on lighting control, with a 4.7 (Figure 4). This indicates that the controllable lighting features of Sense Lab provided students with a profound learning experience. The second-highest score was for the final integrative project, "Lighting Design and Simulation," with a score of 4.6, reflecting positive learning feedback from students regarding the DIALux lighting project at the end of the semester.

Figure 5 shows that students strongly believe Sense Lab enhances their learning outcomes, with 60% strongly agreeing and 40% agreeing. Similarly, 60% of students strongly agree, 36% agree, and 4% are neutral on the effectiveness of PBL in improving their learning experience. Overall, 51% of students agree, and 45% strongly agree that the lighting design course has significantly enhanced their learning outcomes. These results indicate that students strongly affirm the effectiveness of integrating the teaching environment with project-based learning in this course.

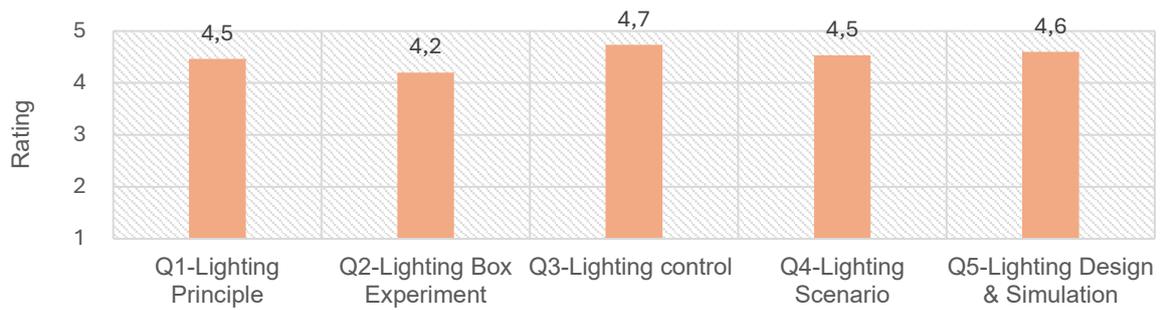


Figure 4. Student self-assessment questionnaire: Learning Outcomes of PBL & Sense Lab

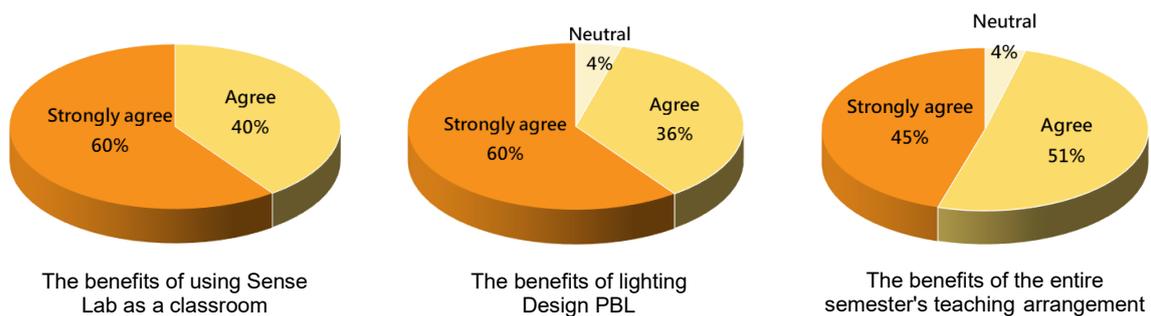


Figure 5. Students' feedback on learning outcomes

CONCLUSION

Lighting design can be a practice-oriented course that solves real problems. This semester's "LightBox" and "Residential Lighting Design & Simulation " use CDIO thematic operation methods. Classroom discussions and practical activities help improve students' professional knowledge, core abilities, classroom participation, and learning satisfaction. In addition, instant debate and feedback on the finished work in class are very helpful to students. Therefore, this year's teaching experience and research results show that lighting teaching that combines laboratory fields with practical projects can indeed help improve learning outcomes; CDIO project-based learning can also help enhance students' ability to apply knowledge.

There are two suggestions for implementing relevant curriculum planning in the future: (1) The teaching field should correspond to the content of the topic practice, and more themes can be designed to effectively use the space hardware and software equipment to diversify and improve teaching effectiveness; (2) Improvements in methods for assessing student learning outcomes have specific implications for evaluating how teaching methods affect student learning outcomes, and further consideration of qualitative research methods and data collection methods are needed.

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BIOGRAPHICAL INFORMATION

Yu-Chan Chao is an Associate Professor at the School of Architecture of Feng Chia University. She has a PhD in architecture, specializing in sustainable architecture and building physical environments, and has over ten years of teaching experience. The courses she teaches have been supported by the Ministry of Education's Teaching Practice Research Program many times. In 2021, she got the Ministry of Education's "Humanities, Arts and Design" Academic Excellence Program. She was consecutively honored as an Outstanding Teacher and Distinguished Teacher at Feng Chia University from 2020 to 2022.

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