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Fostering RF Engineering Competencies Through AI-Integrated Project Based Learning

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***Abstract*— Within the past few years, engineering education has been more and more oriented towards practical, real-world problem solving as well as theoretical education. This change is especially crucial in aspects like electromagnetic wave theory, which supports current 5G and new wireless networks. Nevertheless, Microwave Engineering and Antenna Design courses are commonly lecture-based, and students do not have the skills to solve more complex design problems. In order to close this gap, this work suggests a Project Based Learning (PBL) model of undergraduate RF training. Four patch antenna designs are designed, simulated and analyzed in microstrip with 28 GHz operations, and allow comparison of geometric variations between the designs. In this context, an AI-assisted optimization framework is applied whereby design parameters are produced algorithmically, tested against performance goals, and improved over time to arrive at optimal performance. The most important metrics used to analyze the performance of antennas are return loss (S11), gain, directivity, radiation efficiency, and VSWR. The learning is based on the CDIO (Conceive–Design–Implement–Operate) approach. Findings show enhanced problem-solving skills, design knowledge, and simulation skills and general performance improvement of around 32 percent over traditional approaches.**

***Keywords*—Artificial Intelligence; Active Learning; Comparative Analysis; Design Thinking; Engineering Competencies; CDIO; mmWave; Project Based Learning; Patch Antenna.**

***JEET Category*— Practice**

I. INTRODUCTION

EDUCATION on engineering is shifting out of the lecture-based training and adopting active learning methods focusing more on practical problem solving and competency growth (Zhang et al., 2023; Lavado-Anguera et al., 2024). This shift is especially pertinent to Microwave Engineering and Antenna Design where students must bridge the gap between theory and practice. Nevertheless, these courses tend to be highly theoretical, and offer few chances of practical design, iterative analysis, and independent problem solving. Consequently, students have often experienced difficulties in the application of their knowledge to RF design issues in the real world.Project Based Learning (PBL) can be extensively used to close this gap because PBL involves students in application-based work, which facilitates conceptual knowledge, design thinking, and team-based learning (Fan et al., 2023). Despite the effectiveness of PBL in enhancing learning in general, its use in RF engineering education (especially when combined with Artificial Intelligence) is not common (Ouyang et al., 2023). AI-based assistance can facilitate progressive design to allow a systematic assessment and optimization of engineering parameters.Here, the paper suggests an AI-based PBL model in line with the CDIO (Conceive–Design–Implement–Operate) model. It employs students to design and analyze several 28 GHz microstrip patch antennas; this frequency band is a significant frequency band of 5G millimeter-wave systems (Jameel et al., 2024). This framework uses an iterative design methodology, in which the results of the simulations will inform the further refinement of the parameters using AI-assisted optimization (Ezzulddin et al., 2024). The performance of students is measured on the basis of a structured rubric that encompasses the technical results as well as the critical engineering skills. This method offers a systematic and realistic avenue towards improving RF instruction by incorporating design experience, critical thinking and a net performance gain of about 32% over traditional methodologies, indicating its ability to improve RF teaching through the incorporation of design-based learning.

II. LITERATURE SURVEY

Project Based Learning (PBL) has been well-known as a promising strategy to enhance student engagement, conceptual learning, and practical skills development in engineering learning (Zhang et al., 2023; Lavado-Anguera et al., 2024). It also fosters design thinking and interdisciplinary learning, which are pivotal to address complex engineering problems (Fan et al., 2023). In spite of these benefits, its use in enabling special fields like RF engineering is still minimal.Artificial intelligence (AI) application in education has also contributed to better learning by analyzing data and predicting performance and enhancing students' problem-solving skills (Ouyang et al., 2023). Nevertheless, the use of AI as an active

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design-support tool in the context of student learning processes has not been studied extensively. Recent research in RF engineering has been performed to design and optimize patch antennas made of microstrip at 28 GHz to be used in 5G millimetre-wave applications (Jameel et al., 2024). Antenna parameters, including the optimization of antenna design, have also been optimized using machine learning methods that have shown better performance and efficiency (Ezzulddin et al., 2024). The joint contribution of PBL, AI-assisted optimization, and the RF design to a single educational framework is an unexplored area despite these developments. This gap inspires the current study.

III. Project Based Learning (PBL) Framework

Project Based Learning (PBL) is considered as a systematic method to promote active learning, problem-solving, and the development of practical skills in RF engineering studies (Zhang et al., 2023). It, unlike traditional approaches, allows learners to practice theoretical concepts in the form of real-world design projects.

PBL is applied in this work by designing and analysing microstrip patch antennas at 28 GHz. Several antenna designs are created by students with different geometrical parameters, which encourages comparison and critical analysis and enhanced conceptualization. The framework is based on the CDIO (Conceive–Design–Implement–Operate) model. Students establish design goals, model antenna designs, systematically optimize parameters, and plot performance indicators like return loss, gain, etc.

It includes an AI-assisted part that allows the process of iterative optimization by systematically assessing and optimizing design parameters according to simulation outcomes, which is less dependent on complex analytical equations and simplifies the procedure of determining patch dimensions (Ouyang et al., 2023). The performance of the students is evaluated with the help of a rubric which evaluates the technical results of the work and the engineering skills such as design thinking and analytical skills. Altogether, the framework offers a viable and systematic method to enhance RF learning and design expertise.

IV. Educational Implementation and Outcome Analysis

Learning Alignment and Context

The framework proposed is conceptually consistent with RF engineering classes like Microwave Engineering and Antenna Design, in which students are supposed to acquire both theoretical and design-level knowledge. The courses normally focus on allowing the learners to comprehend the basics of antennas, practice electromagnetic principles, create antenna systems, and analyze the performance parameters. Nonetheless, the exposure to practical and design oriented activities is usually limited, and this limits the effective achievement of these learning objectives.

CO–PO Mapping Perspective

In the traditional course delivery, the main focus is on basic knowledge acquisition with a comparatively small amount of attention to the upper level competencies of design, analysis, and group problem-solving. A combination of a PBL-based approach, as exhibited in this work, offers an avenue to cover a broader spectrum of Program Outcomes. Designing an antenna, simulating, and comparing activities are aimed at supporting results related to the design of any engineering, problem analysis, and the application of modern tools, as well as promoting teamwork and communication skills.

Role of AI-Integrated PBL in Learning

The presence of AI in the PBL model facilitates a guided and iterative learning process. Through simplification of the analytical derivations, AI-assisted optimization allows students to concentrate on comprehending design behavior, interpreting simulation outcomes, and optimization of parameters. This makes it easier to learn more intuitively and application-oriented especially in RF design tasks.

Outcome Implications

The suggested method proves to be able to improve the learning process within RF education. Growths are seen in design knowledge, simulation skills and ability to solve problems with a total performance growth of about 32% as compared to the traditional methods. It means that the AI-aided PBL strategies integration can help to achieve a higher correspondence to the program outcomes and preparation to real-world challenges in the field of engineering.

Importance of Program Outcomes in Engineering

The use of Program Outcomes (POs) is paramount in making sure engineering education is not incompatible with principles of Outcome-Based Education (OBE). They specify the necessary knowledge, skills and competencies that graduates must possess to be able to meet academic and industry demands. Mapping Course Outcomes to POs will allow an effective evaluation of the learning efficiency and the development of the most important skills like problem-solving, design thinking, and the utilization of modern engineering tools. Moreover, extensive PO achievement is necessary in the accreditation processes and indicates the general level of quality and relevancy of the educational program.

V. METHODOLOGY: AI-INTEGRATED PBL APPROACH FOR RF LEARNING

The conventional lecture-based techniques in RF engineering can be characterized by the focus on theoretical knowledge and a lack of practical use. This is capable of inhibiting high level skills like design thinking, problem solving, and collaborative learning. To overcome this, the current study will take a Project Based Learning (PBL) approach with AI-supported design, to improve both the technical and educational result.

PBL-Based Learning Approach

The proposed methodology is designed to be based on a design-oriented learning process, in which learners will be involved in the solution of a real-life RF problem, namely, the design and analysis of microstrip patch antennas at 28 GHz. The strategy is based on the CDIO (Conceive-Design-Implement-Operate) model, which allows making a gradual shift between theoretical knowledge and practice and testing.

Design objectives, model development of the antenna, and analysis through simulation are defined by the students (or learners within the framework). Numerous design options are pursued to stimulate comparison, critical analysis, and refinement. This process encourages active learning and enhances the skills of relating theoretical knowledge with practical design tasks.

AI-Assisted Design Support

A component aided by AI is introduced to facilitate the iterative design process. Simulation feedback is used to generate and optimise design parameters, rather than to make analytical derivations on the dimensions of antennas. This makes the computation less complex and allows more easily visualizing the effect of a parameter on the behavior of the antenna.

Technically, the antenna performance is measured in terms of the following important parameters: return loss (S11), VSWR, gain, directivity and radiation efficiency. These parameters are used as optimizing feedback and comparative analysis.

Addressing Program Outcomes (POs)

PBL methodology provides a wider coverage of Program Outcomes than the traditional methods. The design and simulation activities lead to:

1. PO3 (Design/Development): Antenna design – The development of antenna designs according to design specifications.
2. PO4 (Problem Analysis): Comparison and assessment of the performance of the antennas by simulation.
3. PO5 (Modern Tool Usage): Simulation tools to design and analyse RFs.
4. PO9 (Teamwork): Co-operation in discussion and comparison of designs.
5. PO11 (Project Management): Systematic implementation of design, analysis and refinement.

This approach is integrated and both the technical knowledge and professional competencies are tackled together.

Outcome Evaluation Strategy

Assessment of learning outcomes involves a systematic evaluation process that takes into account the technical performance as well as competency development. The sensitivity of the parameters and trade-offs in the design can be analyzed by comparing several designs of the antenna. The iterative quality of the methodology also contributes to the enhancement of the problem-solving skills, design knowledge, and simulation expertise.

All in all, the methodology shows that implementing the use of AI-aided PBL in RF education offers a progressive way of raising the effectiveness of learning and improving the agreement of the program outcomes.

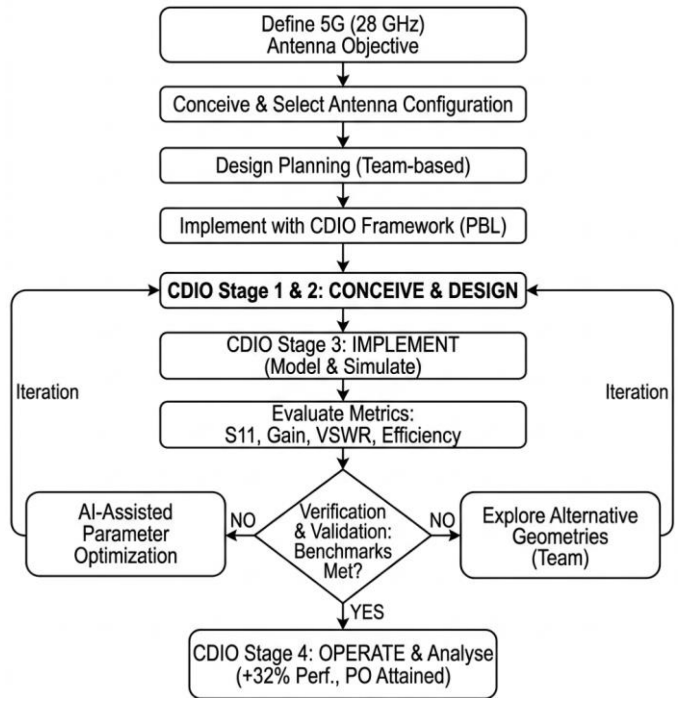

Fig. 1 .Proposed CDIO-based design methodology for a 28 GHz 5G microstrip patch antenna featuring AI-assisted optimization

PO Attainment Analysis

Program Outcomes (POs) are measured to determine the effectiveness of the proposed AI-based PBL framework, and they are measured using the realisation of Course Outcomes (COs) that involve RF design, simulation, and analysis. Technical performance (metrics of antenna design) and competency development (problem-solving, tool usage and collaboration) are evaluated.

Table I shows that the attainment levels are higher in PO1, PO2, PO5, PO9, and PO10, which represents a high level of development in conceptual understanding, simulation proficiency, teamwork and communication. Mediocre achievement in PO3 and PO4 emphasizes a gradual growth of design and analytical abilities in learning by trial and error.

The levels of achievement are categorized according to the institutional standards:

1. Level 3: ≥ 70% attainment (high competency)
2. Level 2: 60-69% achievement (moderate competency)
3. Level 1: Less than 60% achievement (basic competency)

The results indicate that AI-aided PBL is more effective in terms of the overall PO coverage than traditional methods and preconditions the balanced development of technical and professional engineering skills.

TABLE I
PO ATTAINMENT (PROPOSED FRAMEWORK)

Program Outcome	Attainment (%)	Level
PO1 (Engineering Knowledge)	82	3
PO2 (Problem Analysis)	76	3
PO3 (Design/Development)	68	2
PO4 (Investigation)	70	2
PO5 (Modern Tool Usage)	72	3
PO9 (Teamwork)	88	3
PO10 (Communication)	86	3
PO11 (Project Management)	74	3

VI. PERFORMANCE EVALUATION OF PBL-BASED RF LEARNING

The effectiveness of the RF-based learning framework based on PBL is assessed by comparing the results of various designs of microstrip patch antenna at 28 GHz. The antenna designs are shown in Fig. 2 in which various geometrical variations are taken to facilitate comparative learning and analysis.

The acquired performance values of each design of the antennas are summarized in Table II. The findings indicate that the performance of the antenna is stable and consistent in critical parameters that include return loss, gain, directivity, VSWR and radiation efficiency.

As can be seen in Table II, some configurations have a better impedance matching, whereas others have a better radiation efficiency, showing design trade-offs. This difference allows to conduct an effective comparative analysis and understand the impact of geometrical parameters on the performance of the antennas. In general, each model of the antennas performed well in the required frequency range. Learning-wise, the PBL model and structure considerably increase the capacity to interpret the outcomes of simulation, carry out design refinements, and make efficient engineering choices. Optimization with the aid of AI also makes the design process simpler by directing the parameter tuning and minimizing the reliance on sophisticated analytical derivations. The integrated methodology leads to enhanced design knowledge, simulation skills, and capability of solving problems, and overall performance improvement of about 32% over the traditional way of learning. These results demonstrate the usefulness of AI-based PBL in enhancing technical skills and practice-based learning outcomes in RF engineering training.

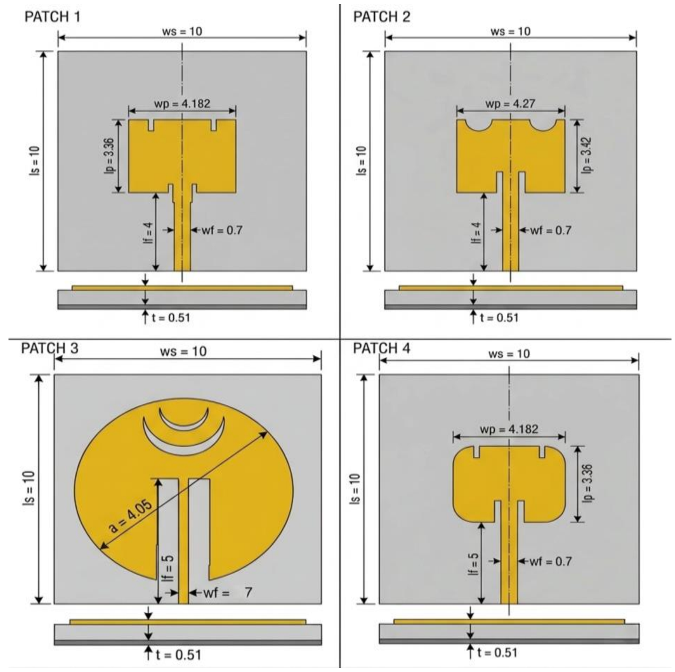

Fig. 2. Microstrip patch antennas configurations designed under the proposed PBL framework

TABLE II
PBL LEARNING RESULT COMPARISON OF PATCH ANTENNAS

Parameter	Patch 1	Patch 2	Patch 3	Patch 4
Resonant Frequency (GHz)	28.044	28.072	28.000	28.004
S11 (dB)	-21.87	-27.30	-21.90	-26.60
VSWR	1.175	1.089	1.170	1.090
Gain (dBi)	7.945	7.927	7.689	7.902
Directivity (dBi)	8.569	8.584	8.108	8.523
Radiation Efficiency	0.865	0.858	0.908	0.866

VII. PBL IMPLEMENTATION

Problem Statement

The students were given the following problem statement: *"Design and analyze a microstrip patch antenna at 28 GHz that can be utilized in 5G millimeter-wave wireless communication applications."* The purpose was to allow students to design electromagnetism, create antenna schemes, model performance with industry standard tools and compare the performance with a predetermined engineering standard.

Process Involved

The activity was carried out among third year Electronics and Communication Engineering students whose strength was 65 and formed into 21 groups. The problem statement was left open-ended on purpose to allow thinking and making decisions independently and collectively. Because students were first time PBL users, the instructors offered systematic help in the initial brainstorming stage. Each group had to come up with their design philosophy, create antenna designs with CST simulation software and optimized with AI-assisted parameter optimization and display their comparative analysis. It was done according to the CDIO framework - conceptualization of the problem and simulation, refinement, and the ultimate performance evaluation.

Rubric for Assessment

A structured rubric of five main parameters (Design Planning, Technical Accuracy, Problem-Solving, Simulation Proficiency and Teamwork and Collaboration) was used as a measure of student performance. The parameters were measured in a scale of 1-5, which allowed an overall analysis of both technical and professional skills acquired within the project activity.

Student Performance Analysis

To quantify the effectiveness of the proposed framework, a comparative analysis is performed between conventional learning methods and the AI-integrated PBL approach.

TABLE III
RUBRIC FOR ASSESSMENT OF STUDENT PERFORMANCE

Assessment Parameter	Description	Scale (1–5)
Design Planning	Ability to plan system architecture and design approach	1–5
Technical Accuracy	Correctness of calculations, modeling, and implementation	1–5
Problem-Solving	Ability to analyze and resolve technical challenges	1–5
Simulation Proficiency	Skill in using tools (MATLAB / HFSS / CST etc.)	1–5
Teamwork and Collaboration	Communication, coordination, and contribution in group	1–5

TABLE IV
COMPARATIVE ANALYSIS OF STUDENT PERFORMANCE

Competency Area	Conventional Method (%)	PBL + AI Framework (%)	Improvement (%)
Problem-Solving Ability	54	78	+24
Design Understanding	51	80	+29
Simulation Proficiency	48	76	+28
Analytical Thinking	55	77	+22
Teamwork & Communication	60	84	+24
Overall Average	53.6	79	+32%

The findings show that there is a marked improvement in all the areas of competency. The greatest improvement is seen in the design comprehension and simulation skills which shows the efficiency of the iterative and application-based learning process. Also, teamwork and communication enhancements are some of the positive features that emphasize how the PBL framework is collaborative.

Generally, the results confirm that AI-based PBL integration results in better learning outcomes, better conceptual knowledge, and engineering skills.

Challenges Faced

The main issues faced in the implementation process were the lack of familiarity with the open-ended problem solving among the first students, time management in both design and simulation processes, as well as the fairness in the team contribution. These were handled by gradual instructor assistance, premeditated schedules and team review gateways.

Student Feedback

The responses of students were mostly positive as they said that they felt more confident using simulation tools, better understood design trade-offs, and developed collaboration abilities. The open-ended nature of the task proved to be a challenge to some of the students, but the systematic nature of the guidance and the review process assisted in creating clarity and engagement over time. The feedback was also obtained formally, at the end of the activity, to inform the further implementations.

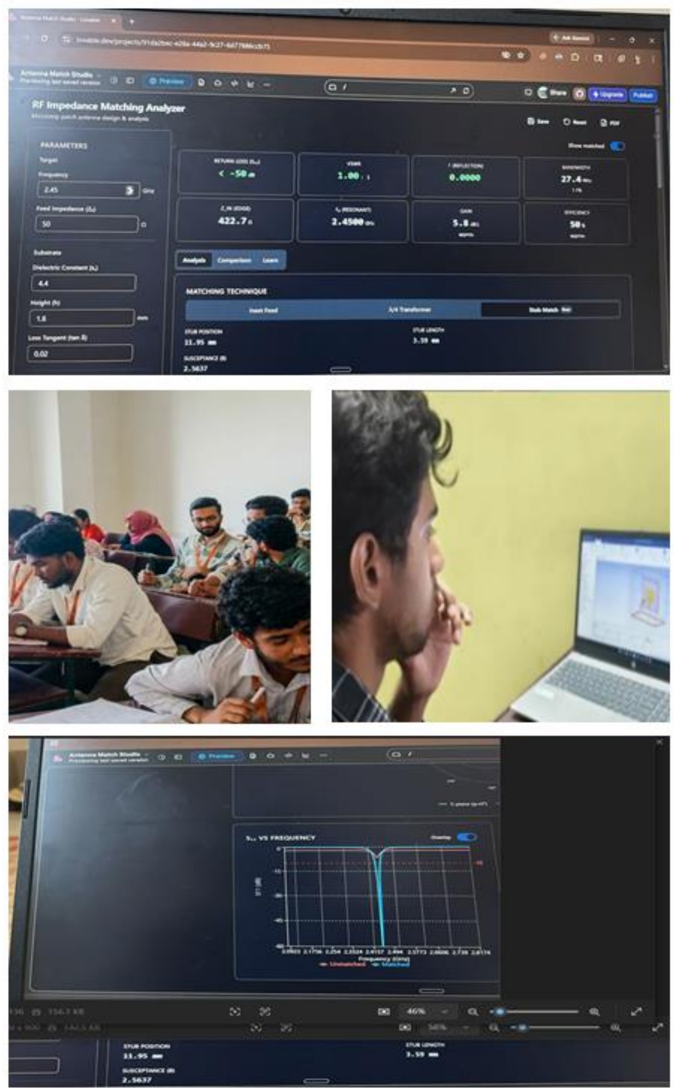

Fig. 3. Classroom activities under the PBL framework illustrating concept delivery, team collaboration, and simulation-based design.

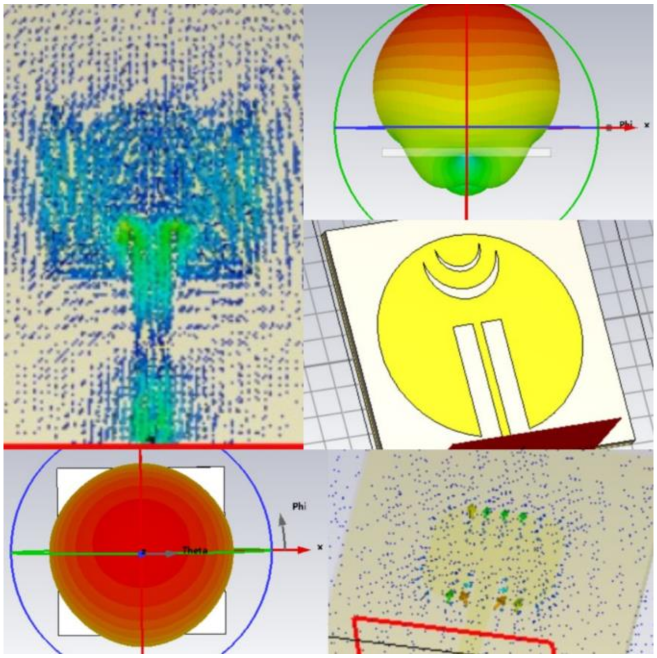

Fig. 4. Implementation phase results where students analyzed surface current and gain plots to iteratively refine design objectives within the CDIO-PBL framework

CONCLUSION

The current research suggested an artificial intelligence-based Project Based Learning (PBL) model to improve the RF engineering education, namely, the design of a patch antenna in 28 GHz microstrip. The framework focuses on the experiential learning by design, simulation, and comparative analysis unlike the traditional lecture based methods.

The findings indicate that the combination of PBL and AI-assisted optimization is the most effective method to enhance conceptual knowledge, simulation skills, and ability to solve problems. The comparative analysis of the various antenna designs helped learners to learn how to trade-off designs and parameter sensitivity.

Educationally, the framework guarantees greater coverage of Program Outcomes especially in design development, problem analysis, and usage of modern tools. The general increase of about 32 percent in the overall performance as observed is an indicator of the efficacy of this method in closing the gap between the theory and its application.

In general, the suggested methodology offers a systematic and extendable framework to empower RF engineering abilities and improve outcome-based-education.

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