Enhancing Student Learning in Robot Path Planning Optimization through Graph-Based Methods

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Enhancing Student Learning in Robot Path Planning Optimization through Graph-based Method

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Abstract
Optimizing robot path planning within computational intelligence and robotics is increasingly important, and graph-based models are at the forefront of this advancement. Teaching these complex subjects poses challenges, addressed in this study through a novel pedagogical approach that combines sparrow-dissection and scaffolding with active, project-based learning (SDS-AL). This method, implemented in a graduate Computational Intelligence course, centers on teaching a visibility graph-based model for robot path planning. Students are provided with source code, which they dissect, understand, and adapt for their specific projects. The course structure encourages students to progress from guided learning to independent project completion, enhancing their practical and theoretical understanding of graph-based techniques. The efficacy of this teaching method is assessed through milestone assignments, presentations, and student feedback, focusing on their comprehension and application of the concepts. Feedback is also gathered on their development and use of neural network models, based on the revision of the initial source code. The teaching strategies are aligned with the course's learning outcomes, confirmed by analyzing the students' projects on graph-based robot path planning. The effectiveness of the course is further evaluated by integrating this analysis with data from the course evaluation system, underscoring the successful application of the graph-based method and the high quality of learning achieved. This integrated approach, merging sparrow-dissection and scaffolding pedagogies with active, project-based involvement, significantly improves student comprehension and application skills in the domain of robot path planning optimization.

1 Introduction

Within the sphere of engineering education, a major emphasis is placed on molding students to become adept professionals. This goal has led to the exploration and adoption of a diverse array of teaching methodologies, including inquiry-based learning [1–4], project-based learning [5–11], collaborative learning [12–15], and flipped learning [16–20]. Each method brings a unique dimension to the educational experience, enriching the learning landscape for students.

Inquiry learning emphasizes student curiosity and investigation, encouraging learners to actively seek knowledge through questioning and exploration. In [1], Xenofontos *et al.* explored student engagement with graphing tasks in a computer-supported environment, highlighting the importance of retrospective action. However, its small sample size limits its generalizability. Notaroš *et al.* [3] integrated MATLAB-based instruction into an electromagnetic course. The assessment was limited to qualitative feedback due to changes in the electrical engineering program. Kollöffel and Jong [4] observed improved conceptual understanding and procedural skills on virtual lab inquiry learning, but its ecological validity was questioned.

Marasc and Bejkat aimed to boost interest in electrical engineering by integrating it with other subjects [5]. Sababha *et al.* [8] implemented project-based learning in an Embedded Systems course, enhancing students' understanding of real-world applications, though lacking specific details on the approach's limitations. Zhang *et al.* [9] used design-oriented PBL in a power electronics course, outlining the course plan and student feedback, but not mentioning the limitations or challenges.

Collaborative Learning emphasizes group dynamics, enhancing understanding through shared ideas. Martin-Gutierrez *et al.* [12] implemented augmented reality in an electrical engineering course. However, the study primarily evaluated immediate student feedback, not exploring long-term educational impact. Hadfield-Menell *et al.* [14] focused on theoretical aspects on cooperative inverse reinforcement learning without real-world validation. Vliet *et al.* [15] investigated the impact of flipped-class pedagogy on student motivation and learning strategies, finding enhanced critical thinking and peer learning. However, these effects were not long-lasting, indicating a need for repeated use.

Jo *et al.* [16] observed increased student participation and interest in flipped classrooms with gaming elements, though without a direct correlation to grades. Castedo *et al.* [17] found that flipped classrooms in an engineering course improved grades and attendance, despite initial student reluctance. Lastly, Gamez-Montero *et al.* [18] noted enhanced class performance and satisfaction in a Fluid Engineering course using flipped classroom methods, combining distance learning with traditional lectures. Each study highlights the varied but positive effects of flipped learning approaches in enhancing student engagement and academic performance.

Despite extensive research, there remains a notable gap in effective teaching methods specifically for using graph-based approaches in robot path planning optimization [21], with existing methods falling short in various aspects. This paper focuses on developing an integrated pedagogical approach tailored for this purpose. We propose a novel method that combines the sparrow-dissection and scaffolding technique with active and project-based learning (SDS-AL). This approach is designed to enhance students' skills in designing, implementing, debugging, and operating graph-based methods for robot path planning, filling a critical void in electrical engineering education.

Sparrow-Dissection and Scaffolding (SDS) in engineering education is an innovative pedagogical approach that combines hands-on experiential learning with scaffolding techniques. This method involves students dissecting real-world engineering problems, akin to how a biologist dissects a sparrow to understand its anatomy. SDS encourages students to deconstruct complex engineering challenges, analyze their components, and gradually build their problem-solving skills. Instructors provide structured support, guidance, and resources throughout the process, ensuring that students remain within their zone of proximal development (ZPD). This approach not only promotes a deeper understanding of engineering principles but also cultivates the critical thinking and self-directed learning skills crucial for engineering professionals. SDS represents a promising way to engage engineering students actively in their education while providing the necessary support to help them thrive in their studies and future careers.

We propose Sparrow-Dissection and Scaffolding with Active Learning (SDS-AL) as an innovative methodology for engineering education. This approach combines hands-on experiential learning, scaffolding techniques, and active learning strategies to create a comprehensive and engaging learning experience for engineering students. In SDS-AL, students actively dissect real-world engineering problems, analogous to a biologist dissecting a sparrow, while participating in group discussions, collaborative problem-solving, and practical activities. Our methodology emphasizes structured support and guidance from instructors to keep students within their zone of proximal development (ZPD) while actively involving them in the learning process. SDS-AL aims to not only deepen students' understanding of engineering principles but also nurture critical thinking, teamwork, and self-directed learning skills vital for their success in engineering. This proposed methodology represents an effective and holistic approach to empower engineering students with the knowledge and skills they need to excel in their studies and future careers.

2 Description of the Course and Project Design

The course ECE 8743 Advanced Robotics serves as a graduate-level course for electrical engineering, computer engineering, and other related engineering students. The course entails two 75-minute lectures per week. With the rapid advancements in computing hardware and the affordability of memory chips, computational intelligence — an integral part of artificial intelligence — is gaining prominence in engineering. This relatively new field finds applications in various engineering and non-engineering disciplines, including robotics [22–27].

The curriculum of this course delves into fundamental structures of computational intelligence techniques, encompassing neural networks, bio-inspired systems, genetic algorithms, and swarm intelligence [28, 29]. Noteworthy is the in-depth exploration of each topic, distinguishing this course from traditional, theory-based engineering programs. Selected vital topics with direct relevance to engineering applications are meticulously covered, highlighting the practical aspects of computational intelligence techniques.

Graph-based path planning is an essential element in numerous real-world applications. It focuses on determining the most efficient route between points within a given space [30]. The objectives for this ongoing project in graph-based path planning are outlined as follows:

- According to the provided algorithms and pseudocode, students are required to draw BOTH a flow-chart and pseudocode to explain graph-based path planning methods.
- Students are suggested to carry out path planning by revising the provided algorithms to create and analyze various graph structure. They are encouraged to adjust the graph construction parameters by varying the locations of vertices and edges to reflect different lines of sight around obstacles. Students should experiment with the placement of seed points and the impact on different graph-based cell structure and path safety margins. They are required to record the efficiency of the paths generated through these structures and discuss their observations; then, they must plot and compare the generated paths and the shortest possible paths derived from these graph structures.

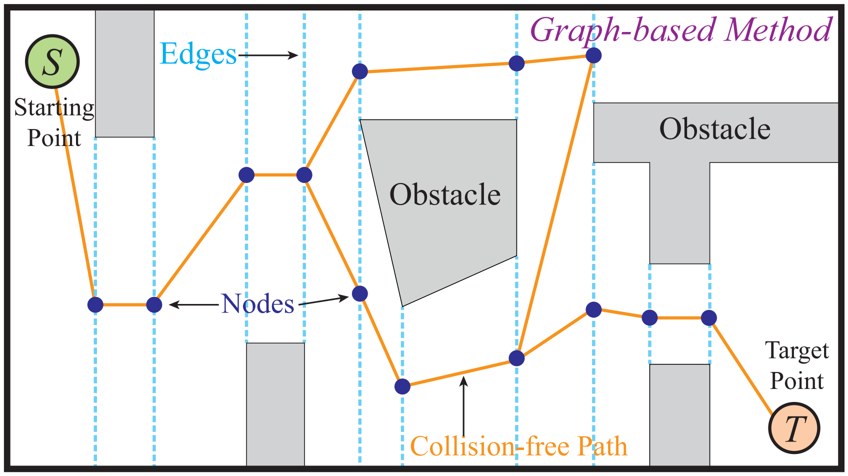

Figure 1: Illustration of a graph-based path planning and navigation algorithm. The environment is partitioning into multiple areas, using graph-based model. The goal is to safely navigate the robot to traverse the obstacle environment from the start (S) point to the target (T).

- Students are encouraged to run the assigned algorithms on simple predefined graphs before revising them to carry out path planning for complex graphs that may include obstacles and varying terrain costs.
- Students are expected to modify and play with the graph properties such as connectivity, density, and type of graph to see the effects on path planning. They should record the results and discuss their observations. Students must visualize the graph and the paths found by the algorithms.
- Students should utilize graph-based path planning algorithms to simulate a robot's trajectory in a given environment. They should use a graph representation to navigate from Start (S) to Target (T) while avoiding obstacles and minimizing the path cost, as seen in Figure 1. Students should clearly write out their path planning algorithm and the graph representation mathematically in the milestone reports.

2.1 Visibility Graphs for Path Planning Model

In this carefully structured project, we instruct students on the utilization of visibility graphs for path planning within a sequence of active, ongoing project-based learning modules, leveraging the sparrow-dissection and scaffolding (SDS) teaching technique. Visibility graphs (VG) are pivotal for computational geometry in path planning, where they serve as a prime method for navigating around obstacles efficiently, especially suited for robotics and AI-driven navigation systems. The visibility graph model, in which nodes represent crucial points like obstacles' vertices and start or goal positions, and edges represent potential paths that are directly "visible" to each other without intersection with obstacles, forms the core of spatial analysis in path planning. This approach is a practical alternative to heuristic-based methods and is instrumental in developing students' spatial intelligence and algorithmic thinking. The SDS method enhances learning by dissecting complex problems into manageable parts, providing a scaffold that supports students as they build their knowledge. Combined with active learning strategies, this project ensures a robust and engaging

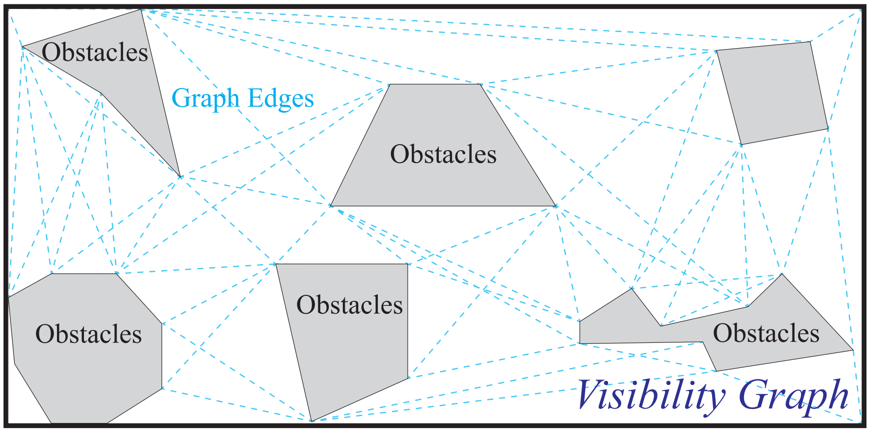

Figure 2: Illustration of visibility graph (VG) based structure. Here students are to use the edges (ligh-blue dashed lines) created to develop a path through the environment.

educational experience. The fundamental principles of the VG approach are described as follows, which are to be integrated and reinforced throughout the project:

A visibility graph is an essential concept in computational geometry, particularly relevant for robot path planning in environments with obstacles, as shown in Figure 2. Formally defined, a visibility graph $G = (V, E)$ is constructed within a two-dimensional space, where the vertex set V encompasses the start point S, the target point T, and the vertices of polygonal obstacles. Edges E in the graph connect pairs of vertices v_i and v_j if a direct line segment between them does not intersect any obstacle. This is mathematically represented for the vertices and edges as

$$V = \{S, T\} \cup \{\text{vertices of all obstacles}\}, \tag{1}$$

$$E = \{(v_i, v_j) | \text{the line segment } v_i v_j \text{ does not intersect obstacles}\}. \tag{2}$$

By translating the pathfinding task into a graph search problem, this graph simplifies navigation in obstacle-laden areas, enabling the application of algorithms like Dijkstra's or A* to efficiently find the shortest path from S to T. This method is highly effective in environments with distinct polygonal obstacles, ensuring an optimal route for robotic traversal.

The project with VG for path planning covers the following items:

- Introduction to VG and their role in path planning.
- Interactive exercises using sample MATLAB code of VG.
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- Revise the VG learned in the classroom to Tangent Graph-based (TG) path planning.
- Analysis of VG in path planning based on scaffolded learning activities.
- Get familiar with VG technique-based robot global path planning.
- Apply the VG technique of robot global path planning learned in the classroom in workspace with a variety of obstacles.

- Improve this VG technique of robot path planning and attempt creation of Reduced Visibility Graph (RVG) algorithm.
- Revision and refinement of VG algorithms in a project-based format for enhanced spatial problem-solving skills.

2.2 Voronoi Diagram for Path Planning Model

This project is designed to guide students through the intricacies of Voronoi diagrams for path planning, using a progressive learning approach characterized by the SDS methodology. Voronoi diagrams are a fundamental construct in computational geometry and are widely used for efficient path planning in robotics, urban planning, and computer simulations, where the goal is to optimize movement within a partitioned space [31]. The Voronoi diagram method partitions a plane with n points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other, as seen in Figure 3. These polygons form a tessellation that is especially useful for understanding and optimizing space usage and path selection in path planning problems. By implementing the SDS technique, we break down the complex concept of Voronoi diagrams into smaller, comprehensible units, creating a scaffold for students to develop a deeper understanding incrementally. Active learning components are integrated to ensure that students engage with the material dynamically, fostering a hands-on approach to learning. The key principles of Voronoi diagrams in the context of path planning are outlined below, forming the basis of the curriculum and project work:

Voronoi diagrams are a key tool in computational geometry, extensively applied in robotics, computer graphics, and geographic information systems. They partition a plane based on proximity to a set of points, termed Voronoi sites. Mathematically, for a set of distinct points $\{p_1, p_2, ..., p_n\}$ in a plane, the Voronoi diagram segments the plane into regions where each region R_i is associated with a site p_i and encompasses all points nearer to p_i than any other site. The Voronoi cell for a site p_i is defined as:

$$R_i = \{x \in R^2 \,|\, \forall j \neq i, d(x, p_i) < d(x, p_j)\} \tag{3}$$

where $d(x, p_i)$ signifies the Euclidean distance between point x and site p_i. The cell edges, equidistant from the nearest two sites, constitute the Voronoi diagram. This diagram is invaluable in understanding spatial distributions and relationships, aiding in robotic path planning for obstacle avoidance, and in network modeling. In robotics, Voronoi diagrams facilitate navigation in intricate environments by guiding paths along cell edges, thus maintaining maximum distance from obstacles symbolized by Voronoi sites.

The project centered on Voronoi diagrams for path planning includes the following elements:

- Comprehensive introduction to Voronoi diagrams and their application in path planning.
- Hands-on activities using sample MATLAB code for generating Voronoi diagrams.
- Detailed examination of the principles of path planning, integrating active learning stages to solidify understanding.

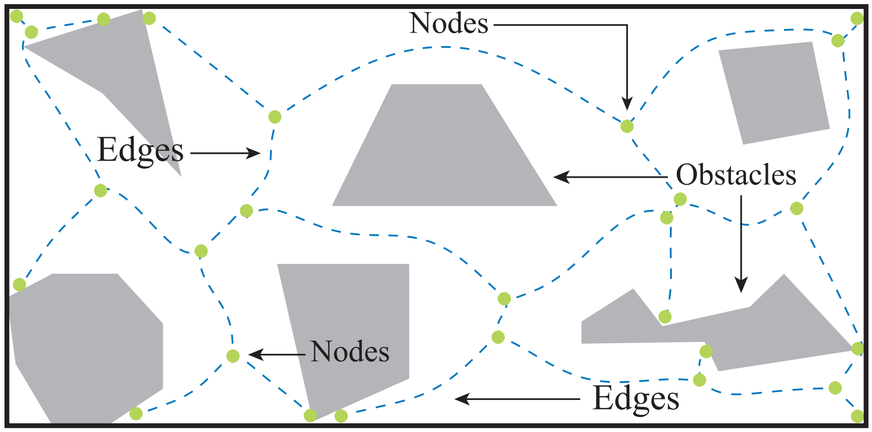

Figure 3: Illustration of Voronoi diagram graph based structure. Here students are to use the edges (dashed lines) created to develop a path through the environment.

- Scaffolded analysis of how Voronoi diagrams facilitate path planning, using step-by-step learning modules.
- Investigation of the parameters influencing Voronoi diagram generation and path optimization.
- Active exploration of different path planning scenarios, employing Voronoi diagrams through project iterations.
- Empirical approaches to constructing Voronoi diagrams, emphasizing application in real-world contexts.
- Progressive refinement of Voronoi diagram algorithms within a project framework to advance spatial reasoning and problem-solving capabilities.

3 The Project-based Pedagogy Infused with Self-Assessment Method

Incorporating the sparrow-dissection and scaffolding approach with active learning (SDS-AL), our pedagogical method uniquely segments the comprehensive project into a series of smaller, interconnected sub-projects. This structure is outlined in detail in Table 1. Each sub-project is designed to not only stand alone but also to serve as a foundational building block for the subsequent tasks, effectively creating a cohesive and cumulative learning experience. This approach, particularly distinct from traditional project-based learning models, emphasizes hands-on involvement and continuous engagement with graph-based path planning methods. The first session, detailed as Sub-Project 1, serves a dual purpose: it provides an orientation to the course structure and sets the stage for the sequential progression of skills and knowledge that culminates in a final, comprehensive project. This methodical progression is aimed at enhancing students' understanding and application of graph-based techniques for robot path planning.

The sub-projects outlined in Table 1 serve as a framework to assess student progression in graph-based algorithms, focusing on MATLAB code implementation for robotic navigation. These projects include developing written reports and engaging in interviews with the instructor, fostering a deeper understanding through practical application and theoretical analysis. Starting

Table 1: Revised Descriptions and Tasks of the Sub-Projects

Sub-Project	Objective	Tasks
SP1: Distribution and exercise of sample MATLAB code	Familiarize students with graph-based methodologies in MATLAB.	• Students are initially assigned a set of MTALB source code, in which it implements various graph based methodologies. • Students are required to understand the MATLAB code completely and run it. • In this stage, instructor is in need of developing a requirements definition, undertaking a context analysis, and exploring design constraints. • The project plan is made. The overall design should be fulfilled.
SP2: Analysis of cell decomposition-based path planning methods	Develop understanding of cell decomposition algorithms for path planning.	• Students are supposed to prepare flowchart of the exact cell decomposition algorithm using block diagrams and schematics. • Students are encouraged to construct code of the cell decomposition algorithm for efficient path planning. • Students are supported to play with the parameters to increase the performance analysis of the algorithm.
SP3: Analysis of visibility graph-based path planning methods	Enhance comprehension of visibility graph algorithms for path planning.	• Students are expected to outline the process of constructing visibility graphs, preparing flowcharts that detail each computational step. • Students are challenged to implement the visibility graph algorithm in code, with an emphasis on handling obstacles and optimizing the shortest path calculation. • Students are supported to test different heuristics for edge weight calculation in visibility graphs to enhance pathfinding for autonomous agents. • Students are invited to apply visibility graphs to practical scenarios, such as robot motion planning and document their findings. • Students should investigate the trade-offs between the accuracy and computational demands of visibility graphs in complex environments with numerous obstacles.
SP4: Analysis of Voronoi diagram graph-based path planning methods	Deepen understanding of Voronoi diagram algorithms for path planning.	• Students are tasked with constructing a flowchart detailing the algorithmic steps for creating Voronoi diagrams, using block diagrams and schematic representations. • Students are encouraged to develop code that generates Voronoi diagrams, focusing on understanding and implementing the underlying geometric principles. • Students are encouraged to manipulate parameters and data sets to observe the changes in the Voronoi diagram, thereby gaining insights into its sensitivity and stability. • Learners are expected to engage in a theoretical study of the applications of Voronoi diagrams in various fields of robotics. • Students should evaluate the computational complexity of their Voronoi diagram algorithms and experiment with optimization techniques to improve efficiency.
SP5: Final project demo, report, and presentation	Final project demo, report, and presentation	• The final deliverable should include a well-documented codebase, a detailed report explaining the integration process, and the rationale behind algorithmic choices. • Students must demonstrate the effectiveness of their integrated system through simulations or real-world testing, showcasing the robot's navigation capabilities in various scenarios. • The project requires students to conduct a thorough performance analysis, comparing the outcomes of their integrated system to standard navigation algorithms.

with SP1, students familiarize themselves with MATLAB code that implements graph-based methods, such as cell decomposition (SP2), visibility graphs (SP3), and Voronoi diagrams (SP4). They are tasked with creating flowcharts, writing code, and fine-tuning parameters to optimize algorithmic performance for path planning. Each sub-project emphasizes a different aspect of graph-based path planning, allowing students to explore various challenges and solutions in robotic navigation. They learn to navigate the trade-offs between computational demands and accuracy, applying these techniques to realistic scenarios. The final project, SP5, is an integration of all these elements. Students must demonstrate the effectiveness of their comprehensive navigation system, comparing it with traditional algorithms. This culminating task consolidates their learning and showcases their ability to apply graph-based methodologies to solve complex navigation problems.

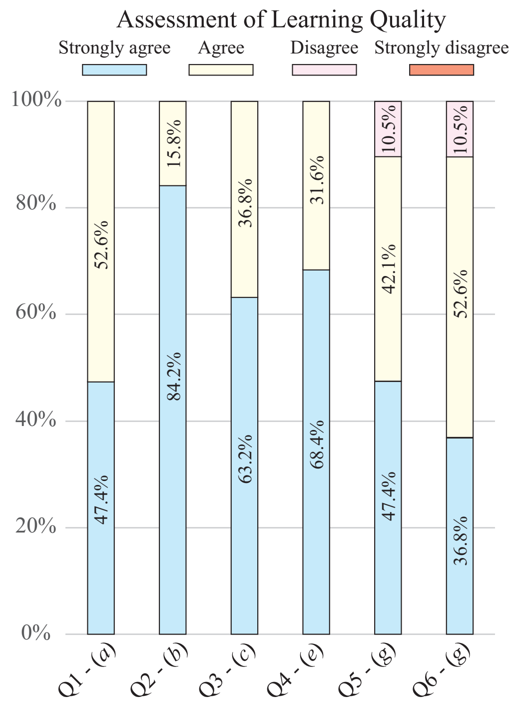

Figure 4: The results from the assessment questionnaire of learning quality.

4 Evaluating Learning Outcomes Through Self-Assessment

The self-assessments designed to measure learning outcomes are closely aligned with ABET standards, forming an integral part of the ABET assessment process. Administered prior to the conclusion of the semester, these assessments serve as a foundation for instructors to enhance teaching methodologies and refine course designs. Most importantly, they contribute to the validation of learning quality and academic success. Within this course, students address six specific questions outlined in Table 2, with corresponding ABET outcomes provided in parentheses for reference.

- Question 1 - "I can understand and use knowledge of mathematics including advanced topics such as differential and integral calculus, linear algebra, discrete math, and differential equations." (Outcome (*a*): An ability to apply knowledge of mathematics, science, and engineering principles to electrical engineering, *i.e.* Knowledge of mathematics encompasses advanced topics typically including differential and integral calculus, linear algebra, complex variables, discrete math, and differential equations.)
- Question 2 - "I can apply formal engineering design methodology to perform the design, experiments and construction of the graph-based approach for robot path planning projects based on experimental test data and interpretation, as well as to analyze and interpret data relating to graph-based approach for robot path planning projects that resolve electrical system problems" (Outcome (*b*): An ability to design and conduct experiments, as well as to analyze and interpret data relating to electrical systems.)
- Question 3 - "I can understand and design basic graph-based models for robot path

planning with assigned a sequence of projects such as visibility graph-based method, Voronoi diagram path planning, and Delaunay triangulation graph method, and work to meet the final goals." (Outcome (*c*): An ability to design electrical systems, components, or processes to meet desired needs).

- Question 4 - "I can understand structures and models of graph-based robot path planning and profoundly understand some important graph-based methodologies such as visibility graph, Voronoi diagram, and Delaunay triangulation graph, and can also identify, formulate, and solve the issues raised in assigned graph-based robot path planning projects" (Outcome (*e*): An ability to identify, formulate, and solve electrical engineering problems.)
- Question 5 - "I have effective communication skills in the context of a collaborative, multi-disciplinary design activity in the project". (Outcome (*g*): An ability to communicate effectively.)
- Question 6 - "I can create professional documentation in connection with the assignments and design project of graph-based robot path planning". (Outcome (*g*): An ability to communicate effectively.)

The results of the assessment questionnaire are presented in Table 2 and are also visually represented in Figure 4. According to the findings in Table 2, students overwhelmingly express either "strong agreement" or "agreement" with statements corresponding to ABET outcomes (*a*), (*b*), (*c*), (*e*), and (*g*). Importantly, the percentages for "strong agreement" are higher in this course for outcomes (*b*), (*c*) and (*e*), when compared to the instructor's experience in teaching other courses. This indicates a potential beneficial influence of the implemented pedagogical approaches on the achievement of these specific outcomes.

Particularly noteworthy is the significant increase in the "strongly agree" responses for Question 2, reaching 84.2%, which is higher than the usual rate. Question 2 is intricately linked to the ability to design and conduct experiments, as well as analyze and interpret data related to electrical systems, as depicted in Figure 4. Furthermore, when compared to the instructor's prior experience teaching the course using a traditional project-based method without sub-projects, sparrow-dissection and scaffolding with active learning (SDS-AL) protocol, and interview sessions for reflection and adjustments), the current course exhibits higher percentages for both "strongly agree" and "agree". This suggests that the integrated approach of project-based pedagogy and the SDS-AL mechanism is significantly more effective than previous models.

For Questions 3 and 4, we observe student percentages of "strongly agree" at 63.2% and 68.4%, respectively, aligning with Outcome (*c*), which focuses on "the ability to design electrical systems, components, or processes to meet desired needs" and Outcome (*e*), which pertains to "the ability to identify, formulate, and solve electrical engineering problems". The slightly lower percentages in "strongly agree" for Questions 3 and 4, compared to Question 2, can be attributed to the enhanced effectiveness of the graph-based approach in designing robot path planning projects. This approach involves the execution of design, experiments, and construction based on experimental test data of graph-based robot path planning and interpretation, contributing to a more robust learning experience.

Outcome (*g*), evaluated through Question 5, assesses communication capabilities during the final

Table 2: The Questionnaire of Students for Assessment of Learning Quality

Questions and ABET Outcomes	Survey			
	Strongly agree	Agree	Disagree	Strongly disagree
Q1 - (*a*)	47.4%	**52.6%**	0%	0%
Q2 - (*b*)	**84.2%**	15.8%	0%	0%
Q3 - (*c*)	**63.2%**	36.8%	0%	0%
Q4 - (*e*)	**68.4%**	31.6%	0%	0%
Q5 - (*g*)	**47.4%**	42.1%	10.5%	0%
Q6 - (*g*)	36.8%	**52.6%**	10.5%	0%

project presentation and teamwork. In this context, the percentage of students expressing "disagreement" is 10.5%, as noted in Question 6, which also aligns with Outcome (*g*). The demand for high-quality written documentation is a key aspect of this project-based class. However, students often find it challenging to familiarize themselves with technical writing, resulting in a 10.5% "disagreement" rate in Question 6, which is linked to Outcome (*g*). This assessment is integral to the development of professional documentation associated with on-going assignments and the design project focusing on graph-based robot path planning. Given the inherent difficulties in oral and technical writing communication skills for graduate students studying the graph-based approach, the percentages of students expressing "strong agreement" are 47.4% and 36.8% for Questions 5 and 6, respectively, both tied to Outcome (*g*).

Engaging in interviews and interactions with students as part of the SDS-AL protocol significantly contributes to enhancing teaching quality. The processes involving writing reflection reports and conducting interviews with the instructor regarding sub-projects have proven instrumental in empowering students. This empowerment is evident in their ability to take ownership of self-regulation cycles related to problem-solving. The approach has notably boosted aspects such as forethought, self-motivation, execution, exploration, discovery, and the learning of artificial intelligence techniques.

5 Conclusion

This paper outlines our approach to instructing a modified version of the project-based methodology, integrating the sparrow-dissection and scaffolding with active learning (SDS-AL) mechanism through graph-based methods for robot path planning. The project-based pedagogies of sparrow-dissection and scaffolding were developed to support students in the design, implementation, debugging, and operation of efficient graph-based methods for robot path planning. To empower students in self-motivated study, the entire project was decomposed into a series of small projects. Each project was followed by students' written milestone reports and interviews based on those reports.

The evaluation of the effectiveness of graph-based methods for robot path planning involved various milestone assignments, reports, presentations, and activities. A comprehensive assessment approach gauged students' comfort with graph-based methods before and after the project. Additionally, feedback was actively sought after each milestone to gather insights into students' experiences with the implementation, development, and application of models in robot path planning. Results from students' self-assessment questionnaires provide compelling evidence that the project-based SDS-AL integrated pedagogy effectively achieves the learning outcomes intended for this advanced robotics course. The approach significantly enhances students' self-motivation, reflection, performance, exploration, and understanding of artificial intelligence techniques.

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