education sciences

Learning to Engineer: Integrating Robotics-Centred Project-Based Learning in Early Undergraduate Education

1. Survey Questions

This supplementary document contains the survey questions used to evaluate the impact of the robotics-based project-based learning (PBL) module on first-year general engineering students. The survey was designed to capture both quantitative and qualitative insights into the students' experiences, focusing on their technical skill development, process-based learning, confidence, and future aspirations in engineering and robotics.

The survey was structured into several sections, each addressing key aspects of the learning module:

- Background and Demographics: Questions aimed at understanding the participants' prior exposure to robotics and engineering concepts (Parts 1–2).
- Quantitative Assessment: Likert scale questions to evaluate students' confidence, interest, and perceived skill development (Parts 2–7).
- Qualitative Reflections: Open-ended questions to capture detailed feedback on specific challenges, successes, and learning outcomes (Part 8).
- Future Aspirations and Impact: Questions exploring students' interest in pursuing advanced robotics projects, further training, or related final-year project topics (Part 9).

These survey questions played a critical role in providing a comprehensive understanding of how the PBL module influenced the students' academic and professional outlooks. By sharing the complete set of survey questions, this supplementary material aims to ensure transparency and enable the replication or adaptation of the study in similar educational contexts.

Survey Questionnaire for PBL Robotics Project Evaluation

Confidentiality Assurance Statement:

Thank you for taking the time to complete this survey. Your honest and constructive feedback is essential for understanding and improving the Project-Based Learning (PBL) approach in our robotics module. Please read the following points carefully:

- Purpose of Data Collection: The information collected will be used for academic research purposes and to enhance the learning experience for future students. Your feedback will contribute to a study on the impact of PBL on student learning and skill development.
- Confidentiality: Although this survey is not anonymous, we assure you that your responses will be treated with the utmost confidentiality. Only the research team and authorized personnel involved in this study will have access to the survey data. Your identity will not be disclosed in any publications or presentations based on this research.
- No Negative Consequences: There will be no negative consequences for providing honest feedback. Your responses will not affect your grades or standing in the program. We encourage you to share your experiences openly to help improve the course and learning outcomes.

- By completing this survey, you are agreeing to participate in this study under the terms described above. We appreciate your contribution and value your input.

Part 1: Demographic and Background Information

1. Your Age: _____

2. Your gender?
o Male
o Female

3. What is your current educational background prior to joining this program? (Select one only)
a) A-Level Student
b) Higher National Diploma (HND) Graduate
c) Former CPE (Chemical and Process Engineering) Student
d) Other (please specify)

4. If you are an A-Level student, what subjects did you take and what are your grades?
a) Subject 1: [] | Grade: []
b) Subject 2: [] | Grade: []
c) Subject 3: [] | Grade: []
d) Additional subjects (if any): [_____]

5. If you are a diploma student, what is your diploma specialization and final classification?
(e.g., Mechanical Engineering, Electrical Engineering, IT, etc.)

6. If you selected Former CPE Student, please specify your previous education pathway and details:
- Educational Background:
  - o A-Level Background
  - o HND Background
- If A-Level Background, list your subjects and grades:
  - o Subject 1: [] | Grade: []
  - o Subject 2: [] | Grade: []
  - o Subject 3: [] | Grade: []
  - o Additional subjects (if any): [_____]
- If HND Background, specify your HND specialization and final classification:
  - o Specialization: [_____]

Part 2: Project Roles and Contributions

7. What role did you take on in your project team?
(Select one)
- Project Leader
- Team Member

8. Do you have any previous experience in the following areas related to the project?

- Computer-Aided Design (3D modeling and 3D printing)
  - o Yes (Please specify: [_____])
  - o No
- Programming (e.g., Arduino, C/C++, or any other programming languages)
  - o Yes (Please specify: [_____])
  - o No
- Electronics (e.g., circuit design, sensor integration, or motor control)
  - o Yes (Please specify: [_____])
  - o No

Background on the System Engineering Process:

The System Engineering Process is a structured approach to managing complex projects. It involves clearly defining project requirements, systematically evaluating design options, developing a project plan (such as using Gantt charts), and performing iterative testing and refinement. This process is commonly used in engineering to ensure that projects are completed efficiently and meet all specifications.

9. Have you ever used a System Engineering Process or a similar structured approach in any of your previous projects?

O Yes (Please specify the type of project and your experience: [_____])

o No

10. What were your primary tasks or responsibilities during the project?

(Select all that apply or provide a brief description)

- Mechanical Design (e.g., 3D modeling, assembly)
- Programming (e.g., writing code, debugging)
- Electronics (e.g., circuit design, soldering, sensor integration)
- Documentation (e.g., recording design decisions, creating diagrams, writing reports)
- Project Management (e.g., scheduling, coordinating team efforts)
- Other (please specify: [_____])

11. How did your role contribute to the project's success, and what challenges did you face in fulfilling your responsibilities?

(Open-ended response: [_____])

Use a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree).

Part 3: Technical Skill Development

12. This project enhanced my understanding of mechanical design (e.g., structural design, 3D printing, and CAD).

13. I gained practical experience with electronics (e.g., circuit design, sensor integration, and motor control).

14. I improved my programming skills (e.g., Arduino or C-based control algorithms).

15. I now understand how to develop autonomous systems, including sensor-actuator integration.

16. The project allowed me to apply theoretical knowledge to practical technical challenges.

Part 4: Process-Based Learning: System Engineering Process

17. I effectively documented project requirements and design decisions throughout the project.
18. I learned how to convert the competition objectives into detailed system requirements that guided our design and development.
19. I developed selection criteria and used a Pugh matrix to evaluate design concepts.
20. The project improved my project management skills, including work breakdown, managing dependencies, and creating Gantt charts.
21. I gained experience in iterative testing and refinement to solve complex problems.
22. I now understand the importance of using a structured process in real-world engineering

Part 5: Teamwork and Collaboration

23. My team collaborated effectively throughout the project, utilizing the diverse skillsets of each member.
24. We managed conflicts and disagreements constructively, considering the different perspectives and experiences of team members.
25. Every member contributed equally to project tasks, considering their individual strengths and areas for development.
26. I had a positive learning experience working with my teammates , benefiting from the varied backgrounds and expertise within the team.

Part 6: Overall Satisfaction and Interest

27. I am satisfied with what I learned through this project.
28. This project increased my interest in robotics and engineering.
29. I would recommend this project-based learning approach to other students.

Part 7: Skills Development Reflection

30. Which areas do you feel you improved the most?
(Select all that apply)

o Mechanical design (e.g., 3D printing, CAD)
o Electronics (e.g., circuit design, sensor integration)
o Programming (e.g., Arduino, C-based algorithms)
o System engineering process (e.g., requirement identification, Pugh matrix)
o Team collaboration
o Project management (e.g., Gantt charts, scheduling)
o Problem-solving
o Others (please specify): [_____]

31. Do you feel that this project prepared you for future engineering challenges?

o Yes
o No
o Not sure
- If "Yes," please explain how: [_____]

- If "No," please share what you think could have better prepared you: [_____]

The key learning outcomes for this project included:

- Reading and interpreting basic engineering assembly and subassembly drawings.
- Evaluating and recommending alternative designs to improve function, cost, and performance.
- Using common hand tools and electronic soldering tools effectively.
- Engaging in team-building activities and cultivating interpersonal relations.
- Functioning as part of a multi-disciplinary team, adhering to project schedules, and completing tasks on time.

32. How well do you think the learning outcomes align with the project's objectives?

(Rate on a 5-point scale: 1 = Not at all, 5 = Fully aligned)

- Please provide any comments or suggestions on how alignment could be improved: [_____]

Part 8: Qualitative Insights

Please provide as much detail as possible in your answers to help us better understand your experiences and perspectives. Detailed responses will give us valuable insights into the challenges you faced, your problem-solving strategies, and the skills you developed.

33. What were the biggest technical challenges you faced (mechanical design, electronics, or programming)?
34. How did you solve process-based challenges (e.g., requirement identification, project management)?
35. What new skills or knowledge do you feel you gained from the project (technical or process-based)?
36. Describe a situation where teamwork played a critical role in overcoming a challenge.
37. What would you do differently if you were to repeat the project, and how did this project influence your approach to learning or problem-solving?
38. How did this project impact your understanding of real-world engineering challenges?
39. Do you believe the skills and knowledge you gained from this project are applicable to future engineering challenges?
    - o Yes (Please specify how: [_____])
    - o No
    - o Not Sure
40. What was the most valuable part of this project for you, and why?

Part 9: Future Aspirations and Impact

41. Has participating in this project increased your interest in engaging with future robotic projects in our General Engineering Program, such as Engineering Design 2 and 4?

- Yes (Please explain how: [_____])
- No
- Not Sure

42. Do you feel more confident about completing future compulsory robotic projects, like Engineering Design 2 and 4, as a result of this experience?
- Yes
- No
- Not Sure

43. How likely are you to consider a robotics-related topic for your final-year project, which is an elective choice, based on your experience in this project?
- Very Likely
- Somewhat Likely
- Neutral
- Somewhat Unlikely
- Very Unlikely

44. Would you be interested in pursuing additional training or learning opportunities in robotics, electronics, or programming beyond the required coursework?
- Yes
- No
- Maybe

45. What aspects of the project most inspired your interest in engineering or robotics?

(Open-ended response: [_____])

2. Abbreviations of Survey Questions in the Quantitative Part

The survey questions used in this study were categorized into thematic areas to comprehensively evaluate the impact of the robotics-based project-based learning (PBL) module. Within the Quantitative Assessment section, it is divided into technical skill development, process-based learning, teamwork, and overall satisfaction. For clarity and brevity, the questions have been mapped to short abbreviations that correspond to their respective themes.

The mapping facilitates easier referencing and analysis, ensuring that the relationships between specific questions and broader learning outcomes are clearly delineated. The following table provides an overview of the question mapping, along with their corresponding themes and abbreviations:

Table S1: Mapping of survey questions in the Quantitative Assessment section, to thematic areas and abbreviations.

Thematic Area	Abbreviation	Survey Question
Technical Skill Development	TSD1	Enhanced understanding of mechanical design, including structural design, 3D printing, and CAD (Q12).
	TSD2	Gained practical experience in electronics, such as circuit design, sensor integration, and motor control (Q13).
	TSD3	Improved programming skills, including Arduino or C-based control algorithms (Q14).

	TSD4	Understanding sensor–actuator integration for autonomous systems development (Q15).
	TSD5	Applied theoretical knowledge to practical technical challenges (Q16).
Process-Based Learning (PBL)	PBL1	Effectively documented project requirements and design decisions (Q17).
	PBL2	Converted competition objectives into detailed system requirements (Q18).
	PBL3	Developed selection criteria and used Pugh Matrix for design evaluation (Q19).
	PBL4	Improved project management skills, including work breakdown and Gantt charts (Q20).
	PBL5	Gained experience in iterative testing and refinement (Q21).
	PBL6	Recognized the importance of structured processes in engineering (Q22).
Teamwork and Collaboration (TC)	TC1	Effectively collaborated as a team, leveraging diverse skillsets (Q23).
	TC2	Constructively managed conflicts and considered diverse perspectives (Q24).
	TC3	Ensured all team members contributed equally based on strengths (Q25).
	TC4	Had a positive learning experience working with teammates (Q26).
Overall Satisfaction and Interest (OSI)	OSI1	Satisfied with the learning experience provided by the project (Q27).
	OSI2	Increased interest in robotics and engineering (Q28).
	OSI3	Would recommend this project-based learning approach to other students (Q29).

This table serves as a guide for interpreting the survey data and understanding the specific aspects of the PBL experience evaluated through the survey responses, particularly the Quantitative Assessment section.

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