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Effectiveness of Project Based Learning Models on Student Interests and Learning Outcomes in Industrial Robot

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Abstract

The resource-intensive aspect of project-based learning (PjBL) has prevented it from becoming more widely accepted in the tertiary education sector. For undergraduate engineering students, this paper introduces a transdisciplinary variant of PjBL through a multidisciplinary challenging engineering challenge requiring the design and construction of a hydraulic robot arm. Using the Chi-square hypothesis test, the robotics-inspired transdisciplinary PjBL variant was first assessed by student feedback. The results showed a statistically significant difference in the proportion of the student feedback in favor of the PjBL for sustainability of transdisciplinary project-based learning, with Chi-square (4, N = 101) = 129.12; p < 0.05. Additionally, the Mann-Whitney U test was used to compare the students' PjBL and PbBL scores U (N = 101) = 192.00, z -p < 0.05. The results showed that PjBL was statistically significantly more effective than PbBL.

Keywords: *project-based learning; robotics education; transdisciplinary perspective; complex engineering problem; problem-based learning.*

Introduction

PjBL, or project-based learning, is a pioneer in fostering 21st-century skills. The development of proactive and adaptive learners who self-direct their performance improvement in a collaborative context to foster creativity in successfully tackling complex problems on an interdisciplinary front are essential for preparing students to become productive members of the global community but are difficult to measure through standardized testing(Bell, 2010). Therefore, as opposed to problem-based learning (PbBL), practical thinking is imparted to students through PjBL, which does not sacrifice core engineering knowledge. As opposed to a problem-based approach, it has been shown that both industry and academics demand an inclination towards project-oriented professional practice (Campus & Penrith, 2003). Therefore, it is essential that PjBL be included as a crucial part of the curricula for university engineering programs (Eguchi, 2015).

PjBL is essentially a dynamic learning paradigm that is built on engaged student planning for independently or cooperatively completing projects that are pertinent to the learning area, with the teacher finally evaluating the project's completion in the form of a product (Yew & Goh, 2016). Project-based learning, in contrast to the instructor-driven role in the

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traditional model of learning, uses a student-centered learning methodology in which the student integrates theory and knowledge into practical skills by using the vehicle of inquiry to move from ideation to the execution of a workable product with the instructor's guidance (Jabarullah & Iqbal Hussain, 2019).

The use of this technique involves a four-phase process: the instructor must define the problem in the first phase; students must conduct research and generate ideas in the second phase to determine the product requirements to address the defined problem; students must then determine and develop a workable product solution in the third phase; the instructor will then assess the students' learning in the final phase (English, 2001). By involving the students in the resolution of challenging engineering issues that resemble real-world situations. PjBL improves students' learning in an interdisciplinary setting by leveraging complex engineering challenges (Nasr M. Ghaleb et al., 2020).

This not only helps students retain necessary knowledge and skills, but it also helps them develop practical skills like communication, teamwork, self-control, and problem-solving across disciplines (Wijayati et al., 2019). As a result, this creative teaching approach gives pupils a variety of professional skills. teamwork, self-directed yet responsible learning, in-depth and well-synthesized knowledge of the subject of interest, and transdisciplinary learning ability (Nawangsari et al., 2022). This supports the need to combine PjBL with a transdisciplinary perspective, which is defined by Ertas et al. as "the integrated use of tools, techniques, and methods from various disciplines" existing simultaneously between disciplines, across different disciplines, and beyond all disciplines (Kolmos, 2006).

The success of any real-world project depends on the integration of all fundamental domains of undergraduate engineering curriculum. The success of a collaborative team of experts from various engineering domains combining their efforts in a transdisciplinary manner is dependent upon a shared understanding of the engineering design process (Sharunova et al., 2019). This concept is highlighted in a variety of sophisticated products, from automobiles to computing centers to the state-of-the-art of domains of Internet of Things (IoT) and artificial intelligence. Only when experts are endowed with a synergistic combination of technical skills and cognitive talents can they undertake such complex problem-solving tasks (Bell, 2010).

Numerous empirical studies have also shown that, despite the fact that engineers from various engineering fields approach a given complex engineering problem in different ways, they all use the same basic design stages and core cognitive processes. Thus, it can be inferred that modern engineering design techniques, particularly those used in industry, are by nature transdisciplinary (Khandakar Chowdhury, Muhammad, Khalid, Md Saifuddin, Zorba, Nizar, 2021). Therefore, the difficult engineering problem used in PjBL at the higher level of education should have this transdisciplinary nature as a distinguishing feature (Cheville et al., 2005).

It is clear that the expanding connections between many academic disciplines have gone beyond the restrictions imposed by the disciplines that make up any given transdisciplinary environment. As a result, interdisciplinary and multidisciplinary domains alone are the source of transdisciplinary education (Dempsey et al., 2003). In this sense, educational robotics has become a powerful transdisciplinary educational tool for PjBL that combines computational thinking and engineering expertise into a single complicated engineering project. In particular, incorporating robotics into engineering projects helps students develop their multidisciplinary abilities while also imparting valuable knowledge that enables them to combine engineering fundamentals for using technology to solve real-world problems (Sumarni et al., 2016). By doing this, students have the ability to turn their theoretical understanding of engineering foundations into a concrete result by learning to develop collaborative yet critical problem-solving skills (Qureshi et al., 2013).

In light of this, this paper presents an effective application of PjBL in a trans-disciplinary setting, where educational robotics was combined with the interdisciplinary fields of mechanical engineering dynamics and fluid mechanics to impart undergraduate engineering education through a challenging engineering problem of the design and construction of a hydraulic robot arm (Alimisis, 2013). This was accomplished by the researchers using a four-module process: management, which involved developing the project rubric, implementation by students under instructor supervision, assessment to determine student performance and to gather student feedback, and evaluation, which involved applying statistical analysis (Campus & Penrith, 2003).

This article's main contribution is the introduction of a transdisciplinary form of PjBL through a multidisciplinary complex engineering challenge necessitating the creation of a hydraulic robot arm. Instead of using the traditional PbBL method, this strategy focuses on connecting two distinct courses (Fluid Mechanics and Engineering Dynamics) with robotics-inspired transdisciplinary PjBL. By using fewer resources—both material and human—to perform and evaluate projects for several courses, this also increased sustainability and the effectiveness of PjB (Campus & Penrith, 2003).

This paper's research findings are divided into seven sections. To highlight the originality of this investigation, Section 2 includes a literature analysis that briefly summarizes the most significant research projects that investigate the applications and consequences of robotics-inspired transdisciplinary PjBL (Atila, 2018). As a result, Section 3 explains the research methodology used in this study by outlining its key components, including the participant information and the mapping of the linked learning outcomes into quantifiable characteristics assessed in student feedback forms (Ertas et al., 2003). Section 3 also provides an explanation of the four processes used to carry out this investigation: management, implementation, assessment, and evaluation (Ibrahim et al., 2018). The investigation's findings are then assessed and described in Section 4. Finally, the conclusions of this paper are compiled in Section 5.

Literature Review

Due to the traditional teaching methods, a survey of engineering education in numerous nations indicated that the engineering disciplines being offered require stringent accreditation standards (Keogh & Galloway, 2004). It has been demonstrated in this case that PjBL is the best option moving forward for the efficient transfer of engineering skills, particularly for loosely organized, interdisciplinary domains (Khandakar et al., 2020). As a result, several research have been carried out to ensure the successful adoption of this new learning modality, particularly in engineering education (Lutters et al., 2014).

For instance, the faculty of mechanical engineering at the Technion has used PjBL in undergraduate courses. Empirical data were gathered to understand how students responded to the PjBL method in terms of emotions, thoughts, behavior, and challenges (Macías-Guarasa et al., 2006). Students not only evaluated their own performance, but it was also noted that PBL instilled in them a sense of ownership over their education via perseverance and hard work. This research, however, was restricted to a freshman-level mechanical engineering introduction course that covered only the most fundamental engineering concepts (Martínez-Monés et al., 2005). Overall, it can be said that teaching methods should be modified to fit the learning preferences of each student so that struggling students can improve their skills and students with higher grades can use their knowledge in real-world situations.

At Aalborg University, Tampere University of Technology, and University of Malaysia, similar initiatives to include PjBL in engineering teaching were successful. These studies, however, lacked a direct student poll to get student opinion and gauge the caliber of their educational experience (Macías-Guarasa et al., 2006). It is important to keep in mind that there are many difficulties associated with teaching in a PjBL environment, many of which are listed in, the main one being the evaluation of student performance. At our university, pipe network analysis was taught to undergraduate mechanical engineering students on the PjBL track using an integrated yet unidirectional approach (Ibrahim et al., 2018).

Based on a thorough analysis of this plan, the mechanical engineering department at our university made additional contributions to the development of project-based learning, particularly in undergraduate engineering, by creating a thorough method for evaluating student performance in the context of PjBL by tying the student feedback questionnaire to the learning outcomes for transdisciplinary education that are inspired by robotics through the use of fifteen important attributes. Some efforts took the use of PjBL a step further by including it into the curriculum design (Rekola & Messo, 2017). Additionally, some studies improved the PjBL approach by including a large number of mini-projects to determine the efficacy of the PjBL assessment. As a result, one such excellent initiative developed a strategy to create project-based curricula for the electronic systems, applying a PjBL approach in an engineering setting (Atila, 2018).

Using an examination of the academic outcomes and the findings of student surveys, the efficacy of the curricula was assessed over the course of four academic years. To capture a broader frame of implications of the strategy, the student survey, however, lacked comprehension in connecting the student responses to a wide range of student learning objectives (Ertas et al., 2003). Project-based learning recently gained a new dimension when it was coupled with transdisciplinary domains. For instance, when multi-course PjBL was used in the department of computer science and involved the creation of computer software, researchers from Montana Tech of the University of Montana had favorable results.

Similarly, a recent research at Nanjing Institute of Technology stressed the value of giving engineering students multidisciplinary education in the form of projects. In a similar vein, Virginia Military Institute implemented another variation of multidisciplinary PjBL that spanned across several semesters and revealed the shortcomings in the conventional, unidirectional curricula. However, it is important to note that these efforts to deploy PjBL in a multi-domain setting lacked information on the project's planning and execution as well as a statistical method to assess the approach's utility value. Amith et al. added something novel to the PjBL approach in this aspect by integrating it into a multi-course setting in undergraduate electrical engineering.

In order to evaluate the success of a multi-course project specifically for education aimed at sustainable development, the study included both the student surveys and statistical analysis. However, the study's primary goal was to evaluate how well students performed in solely the engineering soft skills and project management skills that were mapped by student learning outcomes. Overall, the study proved that any future effort to adopt PjBL from an interdisciplinary perspective is viable.

Additionally, many colleges have included an interdisciplinary approach into their curriculum. Regarding this, a recent study presented empirical findings that demonstrated a transdisciplinary approach to engineering design education built on Boom's Taxonomy. In fact, the most recent study on the effectiveness of interdisciplinary education in a top-tier engineering college, conducted over the course of six semesters or three years, supported empirical evidence that an interdisciplinary approach should be adopted as the direction of engineering education at the tertiary level.

Robotics-based education can be extremely helpful in enhancing student abilities to transform engineering design thought into useful technologies when combined with transdisciplinary education. In this regard, a study examining the trends and challenges facing the educational robotics movement advocated conclusions and recommendations for encouraging teacher and researcher collaboration for an integration of robotics in education to reap the most benefits from a transdisciplinary perspective.

In light of this, a recent PjBL experiment used robotics to teach undergraduate students the fundamentals of electronics, with promising results in terms of developing students' abilities to translate engineering principles into technical improvements. Indeed, building on the importance of robotics in advancing the goals of transdisciplinary engineering education, a recent research project recommended in its key findings that the most effective educational training programs, incorporating "student support services", in advanced manufacturing using robotics calls for continuous experimentation and evaluation of these practices.

This study draws its novelty from the use of a transdisciplinary project-based learning (PjBL) variation, which is referred to in this work, for convenience, as robotics-inspired transdisciplinary PjBL. This study draws its novelty from the concise compilation of literature presented. First, PjBL was used in the study at the tertiary level of education for undergraduate mechanical engineering students in the interdisciplinary technical/hard domains. Second, the PjBL was applied to a challenging engineering issue that called for a grasp of robotics, placing the PjBL in a transdisciplinary setting. Thirdly, the success of this robotics-inspired transdisciplinary PjBL approach was thoroughly examined using the statistical techniques listed below, which evaluated both the robotics-inspired transdisciplinary aspect of this innovative PjBL variant and the project-based aspect:

To determine whether robotics-inspired transdisciplinary PjBL is successful in reaching the associated robotics-inspired transdisciplinary education learning outcomes mapped by the student feedback questionnaire, hypothesis testing will be conducted. Testing your hypotheses will help you determine whether the PjBL and PbBL approaches, which the project and the numerical problems, respectively, represent, are effective by comparing the student scores on the complex engineering problem-based project and the student scores on the associated numerical problems they must solve.

Research Methodology

The four phases of the robotics-inspired transdisciplinary PjBL, which included fluid mechanics, were completed (Rao, J, N, 1987). The difficult engineering challenge was organized according to the project's standards and criteria during the first phase of "management." The students' execution of the project under the guidance of the instructor constituted the second stage of "implementation (C. Fred Hall, 2021)." The "assessment" phase that followed involved gathering student input using a questionnaire that combined PjBL with learning outcomes from a transdisciplinary education program inspired by robotics (Mann & Whitney, 1947). The effectiveness of robotics-inspired transdisciplinary PjBL was then examined in the last step of evaluation using trustworthy statistical analysis methodologies for both the robotics-inspired transdisciplinary education learning outcomes and PjBL versus PbBL (Somerville et al., 2005).

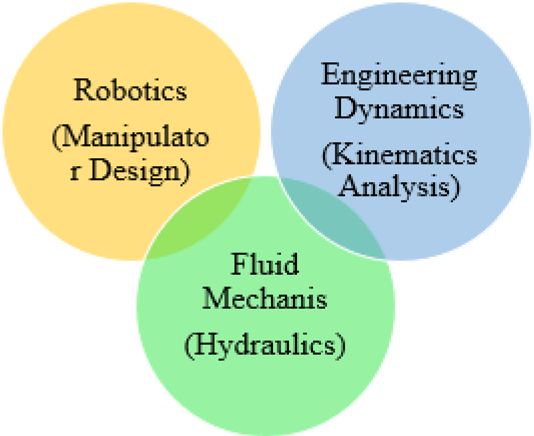

Figure 1. Content.

The project's entire architecture is depicted in Figure 1, which also breaks down the research methodology into three stages that include the phases of management, implementation, assessment, and evaluation (Wiley, 2005). The components of each domain fluid mechanics, engineering dynamics, and robotics that are combined using a transdisciplinary approach are represented by the sub-blocks in Figure 1. In our institution's mechanical engineering department, 101 undergraduate students throughout the course of a full semester (fall 2021–2022) served as the study's subjects. In conjunction with the PbBL technique executed through conventional numerical problems for the Fluid Mechanics undergraduate course, the robotics-inspired transdisciplinary PjBL approach was used to build the hydraulic robot arm semester project (Luna & Chong, 2020). 101 students were divided into 3 groups and examined for both PjBL and PbBL approaches in the research group (Pota, 1992).

By measuring student performance (via questionnaire feedback) in terms of their success in achieving the four main robotics-inspired transdisciplinary education learning outcomes, as illustrated in figure, the effectiveness of the robotics-inspired transdisciplinary PjBL approach was assessed. Based on the framework developed by Sara et al., the constituent feedback question statements are mapped onto these learning outcomes through sixteen qualities.

Management: Complex Engineering Problem

By giving the students a semester-long project based on a challenging engineering challenge in an industrial setting, the PjBL was carried out. The project also included a transdisciplinary learning strategy that was inspired by robotics by exposing the fundamental ideas of robotics that are essential for the effective design and implementation of the solution to the project's complicated engineering problem. The project's robotics module was centered on creating a kinematic model that could be tested experimentally.

According to the project's specifications, a three-degree-offreedom hydraulic robot arm with a multi-pronged hydraulic gripper that is controlled by a piston and levers had to be designed and made. The robotics component of the project specifically called for the creation of a kinematic model that related the location of the gripper from the base as a function of link lengths and angles using the frame assignments shown in Figure. It is important to note that the red, blue, and green axes correspond to the z-axes, x-axes, and y-axes, respectively. The link length from one axis to the next in the manipulator chain was usually along the z-axis (red), and the axes were assigned so that a joint's rotational motion was always along the z-axis (Sharunova, 2017).

In contrast, the project's fluid mechanics (hydraulic) component called for the creation of a kinematic-hydraulic model that connected the position of the gripper wrist from the base as a function of the amount of hydraulic fluid present in the various tubes (Sharunova et al., 2019). The hydraulic robot arm created by the students was required to perform the following task during its demonstration based on these transdisciplinary design deliverables: As illustrated in Figure, use the hydraulic robot arm to pick up and smash the paper cups that were randomly scattered over a 3 by 6 inch space and deposit them in a collection bin close to the center of the area. The students were required to offer a thorough engineering analysis for addressing the fundamental design problem statements listed below while providing these deliverables through the demonstration and the design report.

1. What is the (derived) mathematical relationship between the wrist's position in relation to the base frame and the joint angles?

2. What joint angle values result in the manipulator's maximum extension? What hydraulic column length corresponds to that maximum extension?

3. What are the maximum joint angle restrictions for the manipulator you made? What is the hydraulic column's length in relation to that maximum extension?

4. Know how far the wrist must travel from the base to a goal point.

Implementation: Project Development by the Students

When the project guidelines were released, the students were given roughly two months to submit the project deliverables. Bimonthly evaluations of the students' progress were conducted throughout this time to guarantee that projects were finished on schedule and without sacrificing quality (Andrew et al., 2020). Three major project activities were used to evaluate each student's success in the robotics-inspired transdisciplinary PjBL aspect, as specified in the project rubric.

a. demonstrating and presenting (45% of the final grade): in order to evaluate the students' practical knowledge, teamwork, and presentation abilities with regard to the project design and development.

b. assignment/project (5 percent of the final score): to evaluate the students' attention to detail and readiness for projects on time

c. evaluation of academic/professional communication abilities for drafting technical reports (50% of final score).

The evaluation committee of faculty members assigned grades to the students based on their performance in each of the aforementioned activities. The final student score of 100 points was then calculated using the weighted average of the three major project activities listed in the project rubric figure. Along with the semester project, the students also worked on the typical PbBL assignments, which required them to solve graded numerical questions. As a result, the student performance was calculated as an overall score out of 100 points to compare against the project scores of the students in the PjBL context.

Assessment: Student Grades and Feedback Questionnaire

At the end of the semester, two datasets were gathered: the students' grades for PjBL and PbBL, as well as the feedback from the students via a questionnaire for the assessment of the learning outcomes for the overall robotics-inspired transdisciplinary PjBL approach (Sharunova, Alyona, Butt, Mehwisth & Qureshi, 2018). The first dataset, which represents the student grades, was compiled using the project rubric figure 5 to record the students' performance out of a possible 100 marks for both the PbBl and the PjBL (Sharunova et al., 2022). The effectiveness of project-based learning was examined through a comparison of the student grades for both of these settings (Rekola & Messo, 2017).

The second dataset, a survey of student opinions, was gathered to specifically examine the effectiveness of a transdisciplinary learning strategy inspired by robotics and encompassing the fields of fluid mechanics for effectively disseminating engineering knowledge through the challenging engineering problem of the semester project (Rhee et al., 2020). Based on, a specific questionnaire was created. To ascertain the student viewpoint on achieving the robotics-inspired transdisciplinary education learning outcomes through the robotics and hydraulics based engineering design challenge of the project, it used the Likert scale for each question statement:

Strongly Agree = likert score of 5

Agree = likert score of 4

Neutral = likert score of 3

Strongly disagree = likert score of 1

In order to protect the validity of the survey data, student anonymity was maintained throughout the survey's administration. Table 1 lists the question statements that made up the survey used to get feedback from the students.

Table 1. Transdisciplinary learning assessment questionnaire.

	Question Statements
1	The project provided me with motivation to learn about hydraulics and robotics.
2	The project provided me with opportunities for independent learning and knowledge construction.
3	The project allowed me to explore and make decisions in order to reach a solution
4	Inclusion of the project increased my interest in the course as a whole
5	The project helped me explore meaningful questions related to hydraulics and kinematics
6	The project encouraged me to do independent, out-of-the-box research utilizing all resources (Internet, library, seniors, faculty, et cetera) available to me
7	The project has helped me in becoming a better engineer.
8	I am confident in solving kinematic problems
9	The project provided me with sufficient skills to design a simple hydraulic arm in the future
10	Knowledge acquired through the project will help me if/when I am to work in an industry
11	The project helped me with horizontal knowledge development (i.e., skills not strictly a part of the course, including soft skills).
12	The project helped me with team working skills.
13	The project helped me with time management
14	The project gave me insights into handling projects professionally
15	The project made me an active learner.
16	I prefer project-based learning over lecture-based learning.
17	Working on a project improved my grade for this course.
18	My understanding of hydrostatics is better than my understanding of the other topics of fluid mechanics
19	Had the project not been a part of the course, I would not have learned as much.

Evaluation: Statistical Analysis

Through a graphical analysis of the student feedback questionnaire, the hydraulic robot arm project's transdisciplinary approach's effectiveness was evaluated (Mohd Razali &

Bee Wah, 2011). The analysis, in particular, sought to ascertain how well the initiative met the four learning goals for transdisciplinary education inspired by robotics (refer to figure 2). By classifying the responses to the feedback questionnaire into five Likert-type categories "excellent rating" corresponding to a Likert score of 5, "good rating" corresponding to a Likert score of 4, "neutral rating" corresponding to a Likert score of 3, "satisfactory rating" corresponding to a Likert score of 2, and "poor rating" corresponding to a Likert score of 1 the overall student responses to each of the robotics-inspired trans It is crucial to keep in mind that the feedback questionnaire's question statements (see Section 3.3) were created in a fashion that made it possible to categorize responses using the Likert scale.

The Chi-square test was used to compare expected data to actual data on response categories of the Likert type in order to determine the validity of the classification of the student replies into those categories. This is so that survey results that produce varied expected results can be evaluated effectively using the Chi-square method. In this manner, the test's null hypothesis reads, "There is no difference in the proportion of student feedback for different Likert-type categories of responses," while the test's alternative hypothesis reads, "There is a significant difference in the proportion of student feedback for different Likert-type categories of responses." The raw, independent-variable-drawn, large-sample-size, acquired from independent variables, and mutually exclusive nature of the data type employed in the Chi-square test satisfied the requirements of the Chi-square test. Referring to Equation (1), the equations for the Chi-square (Xc2) statistic are as follows:

$$\chi_c{}^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

101 students' learning performance was evaluated using scores out of a possible 100 points for both the PjBL and PbBL scenarios. Based on the data normality analysis, the impact of PjBL on student learning performance in comparison to PbBL was examined. This is so that the normality test may decide whether to perform a parametric testing analysis or a non-parametric testing analysis on the data. As a result, since the Shapiro-Wilk test is the most useful normality test for big enough data samples, it was specifically used for this study's PjBL and PbBL score data. Accordingly, for PjBL score data, the Shapiro–Wilk test showed a significant departure from normality, W (101) = 0.97, p = 0.017 ($p < 0.05$). On the other hand, for PbBL score data, the Shapiro–Wilk test also showed a significant departure from normality, W (101) = 0.95, p = 0.001 ($p < 0.05$). Thus, the Mann–Whitney U test, termed as the nonparametric equivalent of the Student’s t-test for independent samples , was employed. In fact, for various data scenarios including large sample size, the Mann–Whitney U test is more powerful than Student’s t-test.

The null hypothesis for the Mann-Whitney U test is that "there is no difference between the scores for PjBL and PbBL" while the alternate hypothesis is that "there is a significant difference between the scores for PjBL and PbBL" (Weiner, 2009). The score data met the requirements of the Mann-Whitney U Test by being continuous, consisting of two categorical, independent groups, namely PjBL and PbBL, and being acquired through independence of observations, in addition to having a non-normal distribution. The Mann-Whitney U test's large-sample formulas include.

$$\mu_u = \frac{n_1 \cdot n_2}{2},\ \sigma_u = \frac{n_1 \cdot n_2(n_1 + n_2 + 1)}{1}, z = \frac{U - \mu_u}{\sigma_u}$$

where in Equation (2), sample sizes for PjBL and PbBL, n1 and n2, respectively, are large (more than 10); the Mann–Whitney U test statistic is denoted by U value; µU denotes the mean of U value; and σU denotes the standard deviation of the U value. Through scores in the context of PjBL and PbBL, this study also examined the impact of students' residential status—boarder or day student—on their learning performance. The normality test was used to determine the statistical method for examining how students' PjBL and PbBL were affected by their residential status. Since the Shapiro-Wilk test is the most effective normality test for large enough samples, it was used in this case for both the PjBL and PbBL score data (San-Segundo et al., 2005).

Accordingly, for PjBL score data, the Shapiro–Wilk test showed a significant agreement with normality in case of boarders, $W (76) = 0.98$, $p = 0.131$ ($p > 0.05$), whereas in the case of day scholars, $W (25) = 0.91$, $p = 0.035$ ($p < 0.05$), the test showed a significant departure from normality. On the other hand, for PbBL score data, the Shapiro–Wilk test showed a significant agreement with normality in case of boarders, $W (76) = 0.99$, $p = 0.666$ ($p > 0.05$), Sustainability 2021, 13, 7949 11 of 17 whereas in the case of day scholars, $W (25) = 0.86$, $p = 0.03$ ($p < 0.05$), the test showed significant departure from normality. The Shapiro-Wilk test revealed that the PjBL and PbBL score data for both boarders and day students were not normally distributed, so the Mann-Whitney U test, which is referred to as the non-parametric equivalent of the Student's t-test for independent samples, was used. This is also true since, in a variety of data situations, the Mann-Whitney Test is more effective than the Student's t-test, particularly for high sample sizes (Farid et al., 2021).

The null hypothesis states that "there is no difference between the scores for PjBL/PbBL with respect to status of residence, boarder, or day scholar" when performing the Mann-Whitney U test for both PjBL and PbBL, while the alternate hypothesis states that "there is a significant difference between the scores for PjBL/PbBL with respect to status of residence, boarder, or day scholar" (Sullivan, Gerald & Hardin, 2015). The score data for both PjBL and PbBL met the requirements of the Mann-Whitney U Test by being continuous, consisting of two categorical yet independent groups, namely PjBL and PbBL, and being acquired through independence of observations, in addition to having a non-normal distribution (Sullivan, 2018). The formulas for the Mann-Whitney U test's big sample are the same as those in Equation.

Results and Discussion

This study aimed at advanced kinematics ideas and pressure transfer in the hydraulic system since it was more concerned with design complexity than construction difficulty. However, the hydraulics control was maintained straightforward for the preliminary prototype testing. The current technique, in contrast to earlier research that concentrated on a single course only, focused on coupling two separate courses with robotics, boosting the sustainability and raising the outcomes for numerous courses. The results of each of the analyses are discussed under their following respective heading

Statistical Analysis of the Student Feedback Questionnaire

Figure 2 compares the percentage rating of all student replies for each of the four robotics-inspired complex engineering PjBL projects' four learning outcomes for transdisciplinary education. The findings show that the percentage rating of student replies for each outcome was roughly the same; outcome C received the highest rating. As a result, the findings shown in Figure 7 show that robotics-inspired transdisciplinary education can advance PjBL for undergraduate engineering education.

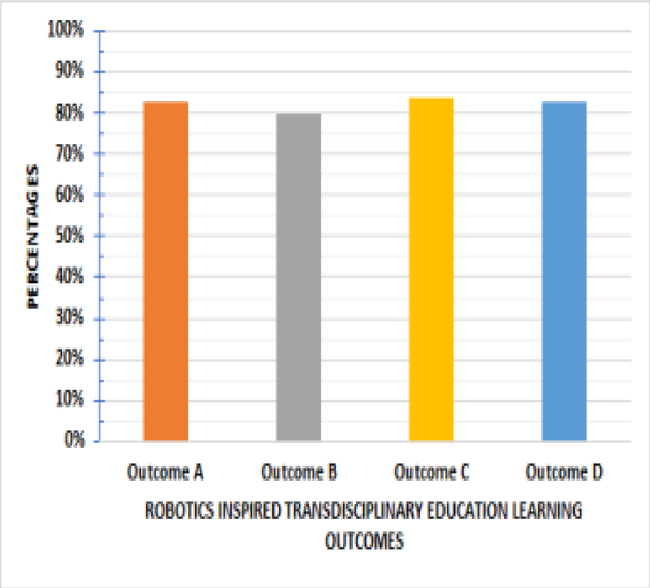

Figure 2. Student feedback questionnaire response evaluation for achieving.

The Chi-Square test was conducted at a 95% confidence level for differences in the proportion of student feedback for different categories of responses pertaining to each of the transdisciplinary outcomes. Table 2 outlines the Chi-square test results for each of the robotics-inspired transdisciplinary education learning outcome.

Table 2. Chi-square hypothesis testing results for robotics-inspired transdisciplinary PjBL.

Variable	X^2 Value	p-Value
Outcome A	130.83	2.59×10^{-27}
Outcome B	150.73	1.42×10^{-31}
Outcome C	105.19	7.72×10^{-22}
Outcome D	129.74	4.42×10^{-27}

Additionally, Figures 2–6 demonstrate the success of PjBL in accomplishing the robotics–inspired transdisciplinary education learning goals, receiving an overall student response rating of “good” from “poor,” “satisfactory,” “neutral,” “good,” and “excellent."

Statistical Analysis of Project-Based Learning Compared to Problem-Based Learning

In order to determine if student performance on PjBL and PbBL differed, the Mann-Whitney U test was performed with a 95% confidence level. Students performed better on PjBL (median = 86.0) than PbBL (median = 65.5), according to their scores. This difference was shown to be statistically significant by a Mann-Whitney U test: U(NPjBL = 101, NPbBL = 101) = 192.00, z = 11.826, p 0.05. As a result, the alternative hypothesis was accepted and the null hypothesis was rejected. This indicates that, as seen in Figure 3, the total student learning performance in the PjBL was higher than that in the PbBL in Figure 3.

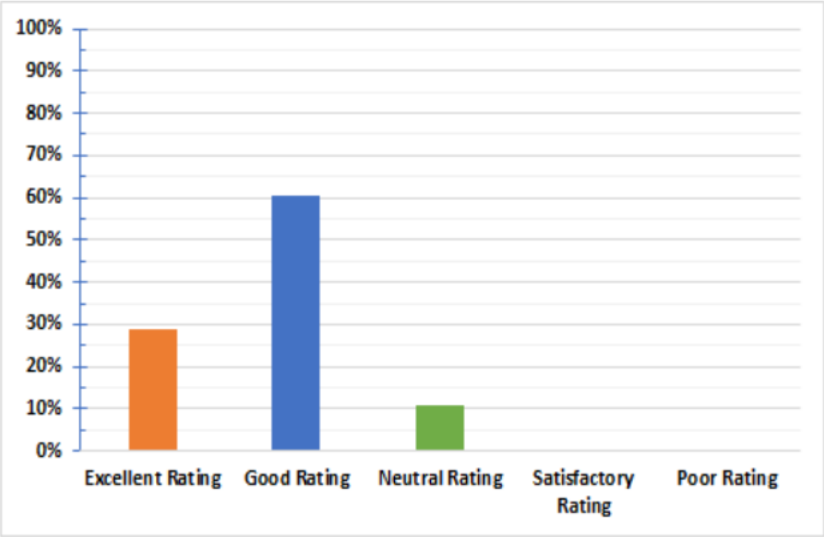

Figure 3. Student feedback for robotics-inspired transdisciplinary education learning outcome A

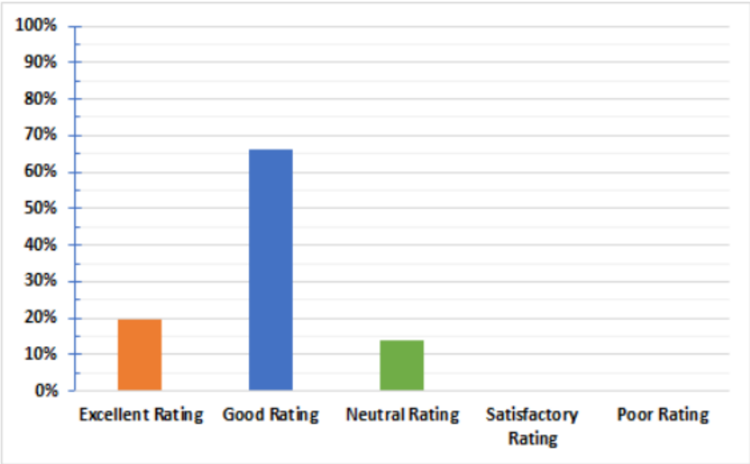

Figure 4. Student feedback for robotics-inspired transdisciplinary education learning outcome B

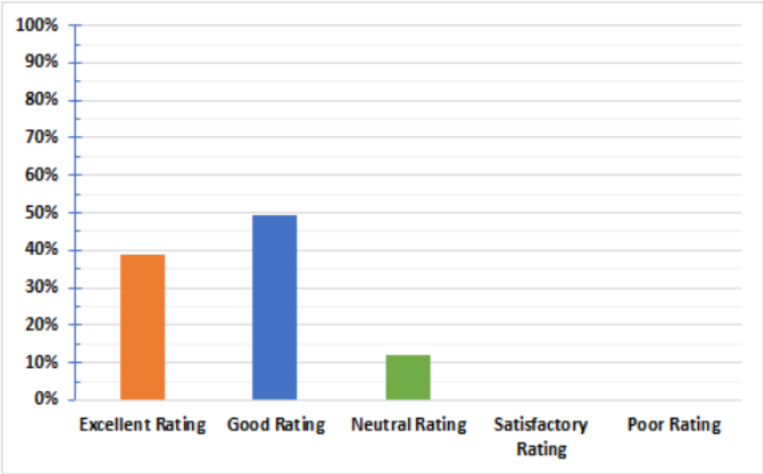

Figure 5. Student feedback for robotics-inspired transdisciplinary education learning outcome C

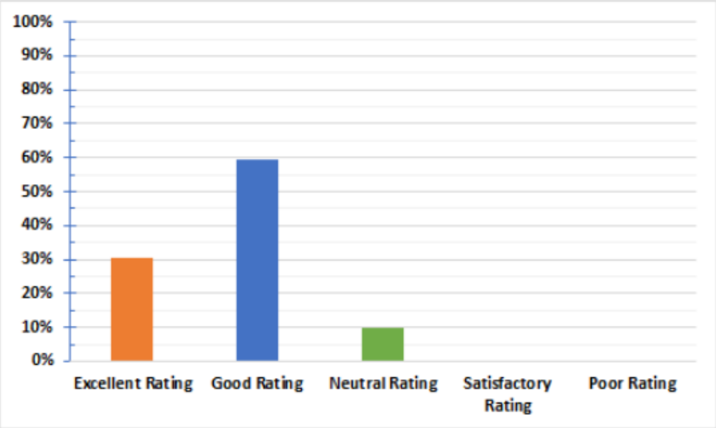

Figure 6. Student feedback for robotics-inspired transdisciplinary education learning outcome D

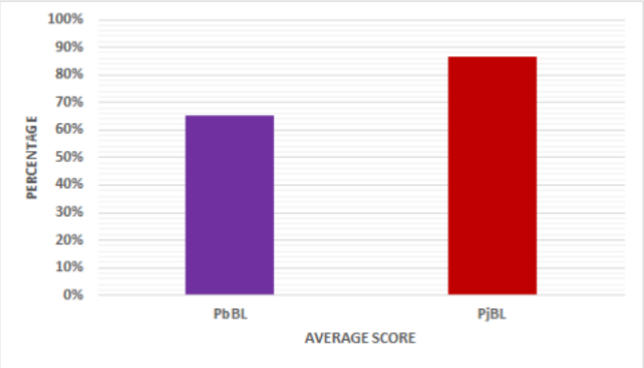

Figure 7. Comparison of average student scores in PjBL and PbBL contexts

Statistical Analysis of the Impact of Student Residential Status on Project-Based Learning and Problem-Based Learning

For both the PjBL and PbBL settings, the Mann-Whitney U test was performed with a 95% confidence level for differences in student performance depending on residence status, boarder or day scholar. Day scholars received lower results (median = 88) than boarding students (median = 86.0). This difference was not statistically significant, according to a Mann-Whitney U test: U (N Boarders = 76, NDay Scholars = 25) = 1133.50, z = 1.453, $p > 0.05$. As a result, the alternate hypothesis was rejected while keeping the null hypothesis. This indicates that the residence situation of the students did not have an impact on their overall learning performance in PjBL. The median PbBL scores for boarders were 65.7, which was higher than the median PbBL scores for day scholars, which were 65.5. This difference was not statistically significant, according to a Mann-Whitney U test: U(NBoarders = 76, N Day Scholars = 25) = 948.5, z = 0.12, $p > 0.05$. As a result, the alternate hypothesis was rejected while keeping the null hypothesis. This demonstrates that the residence situation of the students had no impact on their overall learning performance in PbBL.

Conclusions

In this paper, a unique project-based learning approach known as robotics-inspired transdisciplinary PjBL, or simply robotics-inspired transdisciplinary PjBL, was introduced. The design and construction of a hydraulic robot arm, along with related numerical problems for fluid mechanics over the course of an entire semester, served as the challenging engineering project problem used to test the effectiveness of this variant in teaching engineering knowledge to a total of 101 undergraduate students. The student responses to feedback questionnaires mapping the learning outcomes of robotics-inspired transdisciplinary education were used to evaluate the robotics-inspired transdisciplinary dimension of robotics-inspired transdisciplinary PjBL, which was then subjected to statistical hypothesis testing at a 95% confidence level.

The study confirmed that PjBL is more effective than PbBL in terms of student learning outcomes. It also showed that whether a student was a boarder or a day student had no bearing on their performance in the PbBL and PjBL. Additionally, it demonstrated that PjBL is effective in accomplishing the learning outcomes for transdisciplinary education that are inspired by robotics, with an overall student response rating of "good" from "poor," "satisfactory," "neutral," "good," and "excellent."

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