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Use of Sensor Data of Aircraft Turbine Engine for Education of Aircraft Maintenance

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Aircraft maintenance requires experienced experts with appropriate skills because an aircraft engine is complex and has many parts and components whose conditions require monitoring. Sensor technologies are also required for the maintenance as well as the operation of the aircraft engine as numerous sensors are used to collect and analyze data for maintenance. Therefore, education on how to understand and analyze the data is critical to educating experts in aircraft maintenance. To cultivate such experts, an appropriate educational program is required to improve competencies in the field of aircraft systems. In this study, we adopt the problem-based learning (PBL) method based on sensor data to improve students' ability in practical courses to teach the starting system and hot section inspection (HSI) of the PT6A lightweight turboprop engine manufactured by Pratt & Whitney Canada®. A questionnaire survey was carried out to evaluate professional knowledge, teamwork skills, and the ability to organize, analyze, describe, and solve problems before and after PBL. The results indicate that PBL helped students improve their data analysis abilities. Students showed significant improvements in understanding the operation and function of the engine system and in solving problems with PBL based on sensor data. Education using PBL and sensor data is expected to contribute to developing education on aircraft engine systems and to enhancing the ability to use data related to the systems.

1. Introduction

Aircraft engines require numerous sensors to monitor the pressures and temperatures of important parts and the operations of instruments to ensure safe and optimal flying.(1) The data from these sensors are processed using multi-sensor data processing (MSDP) software that helps control the aircraft control system. Thus, effective maintenance of the aircraft engine requires an understanding of the mechanism of the engine as well as the processing of the data in the system collected from various sensors. A precise understanding of the sensors and their data also allows the development of an efficient and effective maintenance strategy, which in turn requires the development of sensor technology. In particular, in relation to Industry 4.0 technologies, a

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predictive and preventive maintenance strategy is required to improve productivity based on data-driven manufacturing with intelligent sensor systems, deep and machine learning technologies, and digital twins.(2–7)

In the aerospace industry, between 2020 and 2039, there is expected to be a total of approximately 739000 new employees worldwide, of which the Asia-Pacific region will have the largest number of approximately 253000 new employees.(8) The demand for aviation manufacturing and maintenance technicians is expected to continue to grow even with the COVID-19 pandemic. To meet such demand, it is necessary to develop and improve education programs corresponding to Industry 4.0 technologies because technicians require skills to deal with problems related to analyzing a large amount of data for the maintenance of airplanes.(9,10) Therefore, it is important to have appropriate educational programs in which new skills and competencies are taught along with appropriate sensor data sets for teaching aircraft maintenance.

Therefore, we explore the effectiveness of the problem-based learning (PBL) method with various sensor data in aviation technology courses on aircraft maintenance, because PBL has been used in various fields of education.(11–14) To find how well students understand knowledge related to aircraft maintenance through self-learning, we gave them statements associated with PBL and data analysis to read, and they graded their level of understanding. The learning concept of "knowing and reflection in action" in PBL helps provide students with professional knowledge and skills through hands-on operation and on-site training, which are particularly important in aircraft maintenance and dealing with numerous sensor data.(15,16) By using sensor data and applying the data to PBL to educate students in aerospace technology, students can learn how to understand the problems of aircraft engines from anomalous sensor data and how to respond to these problems. The results of this study are expected to help students learn the necessary skills and enhance competencies required in the aerospace industry.

2. Research Methods

2.1 Sensor data

In two practice courses in which instruction is given on the starting system of the PT6A-60 engine (Pratt & Whitney Canada®) and hot section inspection (HSI), the engine installed in a Beech KingAir 350i aircraft is chosen for teaching and practicing aircraft maintenance. It has 1050 shaft horsepower (SHP) with a maximum propeller speed of 2200 rpm. For the engine, HSI is carried out to examine the condition of the combustion chamber, the vane rings, the compressor turbine disk, the power turbine, the temperature sensing system, the shroud segment, and the turbine blades, for which faults can be diagnosed from sensor data.(17–19) The sensor data are collected from various sensors including borescope (turbine blades), temperature, pressure (power turbine and temperature sensing system), rotor speed, fuel flow, and gas leakage (compressor) sensors.

2.2 Questionnaire survey

To explore the changes in students' learning and problem-solving ability when instructed by the PBL method based on the use of sensor data, a questionnaire survey was carried out to understand how well students understood the sensor data and their use in PBL about the parts and operation of the aircraft.

The questionnaire contained 23 statements to evaluate the understanding of student knowledge of the aircraft engine (Table 1). The statements presented in Table 1 were based on Carmines and Zeller's results.(20) The statements were grouped into the following categories: professional knowledge, problem organization, ability to analyze problems, ability to describe problems, ability to solve problems, and teamwork.(21–23) Jenkins and Taber(24) stated that the reliability of a questionnaire survey can be ensured with a 5-point Likert scale. Thus, each statement was scored with a 5-point Likert scale of strongly agree (5 points), agree (4 points), neutral (3 points), disagree (2 points), and strongly disagree (1 point). The questionnaires were distributed to 45 second- and third-year university students with a basic understanding of the maintenance of aircraft engines. It was assumed that no other external factors, such as emotional and physical stress or gender, affected the results.

Table 1
Statements in the questionnaire of this study.

Category	Number	Statement
Professional knowledge	1	I understand the meaning of a hung start.
	2	I understand the meaning of a hot start.
	3	I understand the operation of starters and generators.
	4	I understand the operation of the engine starting system.
	5	I understand the motoring conditions.
Problem organization	6	For engine starting systems/HSI, I can usually find the crux of the problem.
	7	When researching engine starting systems/HSI, I can quickly find information.
	8	When studying the engine starting system, I can imagine the problems that may be encountered.
	9	I can quickly complete the analysis and classification of the maintenance manual.
Problem analysis	10	I can learn unknown information from the data of the engine starting system/HSI.
	11	I can infer the function of the engine starting system/HSI from data collection.
	12	I have confidence in logical thinking about the engine starting system/HSI.
	13	I can find problems that others have not found.
Problem description	14	I can discuss problems through reverse thinking.
	15	I can give my opinion on the current situation.
	16	I discuss issues with the PT6A starting system/HSI with other students.
	17	I choose to find information and a solution when encountering problems.
Problem solving	18	I formulate a solution strategy and a review method in the process of solving the problem.
	19	I keep up with the progress of implementation in the problem solving process.
	20	I understand the trends in engine performance and troubleshooting.
Teamwork	21	I understand the meaning of what other people say in their research on the starting system/HSI.
	22	I can discuss and solve problems with others when researching the starting system/HSI.
	23	I coordinate work matters or cooperate with others on assignments.

Table 2
Internal consistency of the categories in the questionnaire.

Category	Statement numbers	Cronbach α
Professional knowledge	1–5	—
Problem organization	6–9	0.67
Problem analysis	10–13	0.75
Problem description	14–17	0.74
Problem solving	18–21	0.81
Teamwork	21–23	0.82
Total	23	0.90

Table 3
Statements of students' professional knowledge and their scores before and after PBL.

Statement No.	Statement	Before PBL	After PBL
1	I understand the meaning of a hung start.	2.17	2.86
2	I understand the meaning of a hot start.	3.30	3.56
3	I understand the operation of starters and generators.	2.07	2.48
4	I understand the operation of the engine starting system.	3.62	3.46
5	I understand the motoring conditions.	3.40	3.94
	Average score	2.91	3.26

Statements in each category in the questionnaire were validated for their internal consistency with Cronbach's α. It is generally agreed that a Cronbach α of above 0.7 indicates acceptable consistency. All statements except those in the category of problem organization were found to be valid for this research (Tables 2 and 3).(25)

2.3 Learning through PBL

PBL is used to encourage students' critical thinking and problem solving in various fields such as health sciences, business studies, and engineering. PBL is increasing in popularity because it has been found to engage students in collaborative learning. Students trained with PBL exhibit longer-term knowledge retention and better learning outcomes, such as performance and skills, than those trained with the traditional learning method.(26–29) The process by which PBL was used in this study is as follows.

(A) Discovering a problem

The 45 students were divided into seven groups to discuss problems that might have occurred in the turbine engine. Each group defines an issue in engine parts maintenance based on the sensor data.

(B) Defining a major problem

After defining a possible problem in the turbine engine through discussion, students attempted to find information on the problem and a solution. The students were instructed to find problems related to starters and generators, the operation of the engine system, and the motoring condition by using the sensor data. Then, each group shared their findings obtained from the internet and a literature research and decided on the problem to attempt to solve.

(C) Solving the problem

A hung start was chosen as the problem to solve. Each group researched the solutions to problems that might cause a hung start. Such problems include those with the action part of the oil system, the compressor pressure, and the airflow, as well as abnormal signals of the starting motor. Finally, each group proposed possible solutions for different problems that might cause a hung start.

(D) Presenting the solution

Through a group discussion and presentation, different solutions to the problem proposed by each group were incorporated to obtain an overall solution.

(E) Summary and evaluation

3. Results and Discussion

3.1 Professional knowledge

Table 3 shows the average score for professional knowledge of the aircraft engine before and after applying PBL. The average score for statement 1 (meaning of a hung start) after PBL is 2.86, which is 0.69 higher than that before PBL. The scores for statements 2, 3, and 5 also increased by 0.26, 0.41, and 0.54, respectively, with similar standard deviations. The scores were improved by 15–32% after applying PBL. This indicates that PBL helped improve students' knowledge of a hung start, hot start, parts, and motor conditions and their understanding of how the related incidents were reflected in the sensor data. However, the score for category 4 decreased by 0.16, which means that students did not obtain appropriate knowledge about the operation of the engine starting system. Understanding the operation of the engine requires practice that cannot be acquired by research and examining the data. This may be why the score did not improve after PBL.

3.2 Problem organization

As shown in Table 4, the average score for problem organization improved from 3.16 to 3.73 for knowledge of the PT6A starting system and from 3.16 to 3.41 for PT6A HSI after PBL. The

Table 4
Scores for the statements about students' ability to organize problems.

Statement No.	Statement	PT6A starting system		PT6A HSI	
		Before PBL	After PBL	Before PBL	After PBL
6	For engine starting systems/HSI, I can usually find the crux of the problem.	3.09	3.66	3.29	3.41
7	When researching engine starting systems/HSI, I can quickly find information.	3.17	3.76	3.09	3.31
8	When studying the engine starting system, I can imagine the problems that may be encountered.	3.21	3.78	3.09	3.52
Average		3.16	3.73	3.16	3.41

scores for all the statements in this category increased significantly, revealing that PBL enhances the students' ability to find problems and their solutions based on sensor data.

3.3 Problem analysis

Table 5 shows an increase in the average score for the statements in this category. The average score increased from 3.32 to 3.71 for knowledge of the PT6A starting system and from 3.25 to 3.42 for PT6A HSI after PBL. With PBL, the students improved their ability to analyze problems in general, especially logical thinking (statement 12). PBL helps students understand instructions in the manual, analyze data from the sensors, and infer the function of the system.

3.4 Problem description

The average score for describing and discussing problems increased from 3.50 to 3.83 for knowledge of the PT6A starting system and from 3.46 to 3.61 for PT6A HSI after PBL. The ability to find problems and discuss them, giving their opinions, improved with PBL (Table 6).

Table 5
Scores for the statements about students' ability to analyze problems.

Statement No.	Statement	PT6A starting system		PT6A HSI	
		Before PBL	After PBL	Before PBL	After PBL
9	I can quickly complete the analysis and classification of the maintenance manual.	3.15	3.56	3.27	3.45
10	I can learn unknown information from the data of the engine starting system/HSI.	3.36	3.64	3.38	3.48
11	I can infer the function of the engine starting system/HSI from data collection.	3.51	3.78	3.24	3.41
12	I have confidence in my logical thinking about the engine starting system/HSI.	3.28	3.86	3.11	3.33
	Average	3.32	3.71	3.25	3.42

Table 6
Scores for the statements about students' ability to describe problems.

Statement No.	Statement	PT6A starting system		PT6A HSI	
		Before PBL	After PBL	Before PBL	After PBL
13	I can find problems that others have not found.	3.21	3.68	3.36	3.40
14	I can discuss problems through reverse thinking.	3.47	3.78	3.18	3.50
15	I can give my opinion on the current situation.	3.62	3.96	3.62	3.71
16	I discuss issues with the PT6A starting system/HSI with other students.	3.70	3.90	3.69	3.84
	Average	3.50	3.83	3.46	3.61

3.5 Problem solving

Students improved their ability to solve engine system failures after PBL. The average score for this category increased from 3.63 to 3.90 for knowledge of the PT6A starting system and from 3.56 to 3.72 for PT6A HSI. It was found that PBL helped students find effective solutions to problems (Table 7).

3.6 Teamwork

The average score for this category increased from 4.04 to 4.05 for knowledge of the PT6A starting system and from 3.93 to 3.98 for PT6A HSI. The average score for the students' teamwork did not change significantly after PBL; students showed similar scores for discussion while researching solutions and collaborating with others. This implies that even before PBL, students were aware of the importance of teamwork for finding and solving problems (Table 8).

Students improved their ability in each category, as shown in Table 9. As a result of PBL, the average score increased from 3.53 to 3.84 for knowledge of the PT6A starting system and from

Table 7
Scores for the statements about students' ability to solve problems.

Statement No.	Statement	PT6A starting system		PT6A HSI	
		Before PBL	After PBL	Before PBL	After PBL
17	I choose to find information and a solution when encountering problems.	3.85	4.04	3.76	3.93
18	I formulate a solution strategy and a review method in the process of solving the problem.	3.62	3.88	3.56	3.78
19	I keep up with the progress of implementation in the process of solving the problem.	3.68	3.90	3.49	3.64
20	I understand the trends in engine performance and troubleshooting.	3.36	3.76	3.44	3.52
Average		3.63	3.90	3.56	3.72

Table 8
Scores for the statements about students' teamwork.

Statement No.	Statement	PT6A starting system		PT6A HSI	
		Before PBL	After PBL	Before PBL	After PBL
21	I understand the meaning of what other people say about their research on the starting system/HSI.	3.91	4.08	3.84	4.00
22	I can discuss and solve problems with others when researching the starting system/HSI.	4.19	4.10	4.04	4.00
23	I coordinate work matters or cooperate with others on assignments	4.02	3.98	3.91	3.93
Average		4.04	4.05	3.93	3.98

Table 9
Average scores for the categories of the questionnaire.

Category	PT6A starting system		PT6A HSI	
	Before PBL	After PBL	Before PBL	After PBL
Professional knowledge	2.91	3.26	—	—
Problem organization	3.16	3.73	3.16	3.41
Problem analysis	3.32	3.71	3.25	3.42
Problem description	3.50	3.83	3.46	3.61
Problem solving	3.63	3.90	3.56	3.72
Teamwork	4.04	4.05	3.93	3.98
Average	3.53	3.84	3.47	3.63

3.47 to 3.63 for PT6A HSI. Professional knowledge, problem organization, problem analysis, problem description, and problem solving were significantly enhanced after PBL, while teamwork showed similar scores before and after PBL. The result implies that PBL helped students improve their ability through the course. Note that the ability of problem analysis through data collection and analysis was improved, which is critical in the maintenance of aircraft engines.

3.7 Improvement of understanding due to PBL

To find the significance of the difference in the understanding of the PT6A starting system before and after applying PBL, we performed the paired-sample t-test, the results of which are shown in Table 10. This test is used to compare the mean difference between two groups of dependent samples from the same population. Regarding the difference in the students' understanding before and after PBL, the null hypothesis is $H\_0:u\_1 = u\_2$, i.e., no significant difference in the learning effect, while the alternative hypothesis is $H\_a:u\_1 \neq u\_2$. The questionnaire in this study was designed to establish by how much students' professional knowledge is improved after implementing PBL.[30,31]

The paired-sample t-test results of statements 6, 7, 8, 9, 12, 13, 15, 18, and 20 show p-values of less than 0.05, indicating a significant difference. For statements 10, 11, 14, 16, 17, and 19, the p-values are greater than 0.05, but it is observed that PBL improved the students' knowledge to a certain extent. In terms of teamwork, the average pre-and post-test scores after PBL (statements 21, 22, and 23) are 3.91 or above, indicating that students have a high ability in teamwork in general.

Table 11 shows how much the knowledge of the PT6A HSI was improved by applying PBL by using paired-sample t-test. The scores for statements 6, 7, 8, 9, 12, 14, 16, 17, 18, 19, and 21 show significant differences before and after PBL with p-values of less than 0.05. The scores for statements 13, 15, and 20 do not show significant differences and have p-values greater than 0.05. However, the students improved their knowledge to a certain extent. The scores for statements 22 and 23 indicate that students understood teamwork better after PBL.

Table 10
Averages, standard deviations, and t-test results of the questionnaire survey before and after PBL regarding the PT6A starting system ($n = 45$).

Number	Before PBL		After PBL		t-test result	
	Average	Standard deviation	Average	Standard deviation	t-value	p
6	3.09	0.731	3.66	0.816	−3.566**	0.001
7	3.17	0.608	3.76	0.751	−4.901***	0.000
8	3.21	0.717	3.78	0.794	−3.792***	0.000
9	3.15	0.695	3.56	0.761	−2.456*	0.019
10	3.36	0.825	3.64	0.749	−2.007	0.051
11	3.51	0.705	3.78	0.707	−1.808	0.078
12	3.28	0.864	3.86	0.882	−3.939***	0.000
13	3.21	0.656	3.68	0.767	−2.979**	0.005
14	3.47	0.773	3.78	0.782	−1.701	0.096
15	3.62	0.801	3.96	0.749	−2.964**	0.005
16	3.70	0.687	3.90	0.677	−1.675	0.102
17	3.85	0.751	4.04	0.67	−1.675	0.102
18	3.62	0.701	3.88	0.697	−2.482*	0.017
19	3.68	0.754	3.90	0.731	−1.776	0.083
20	3.36	0.906	3.76	0.898	−2.253*	0.030
21	3.91	0.759	4.08	0.696	−1.567	0.125
22	4.19	0.66	4.10	0.66	0.000	1.000
23	4.02	0.78	3.98	0.795	−0.387	0.701

$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Table 11
Averages, standard deviations, and t-test results of the questionnaire survey before and after PBL regarding PT6A HSI ($n = 45$).

Number	Before PBL		After PBL		t-test result	
	Average	Standard deviation	Average	Standard deviation	t-value	p
6	3.29	0.695	3.41	0.806	−2.622*	0.012
7	3.09	0.763	3.31	0.815	−2.362*	0.023
8	3.09	0.668	3.52	0.815	−4.243***	0.000
9	3.27	0.677	3.45	0.845	−2.562*	0.013
10	3.38	0.650	3.48	0.780	−2.377*	0.022
11	3.24	0.802	3.41	0.853	−3.090**	0.003
12	3.11	0.804	3.33	0.944	−3.090**	0.003
13	3.36	0.609	3.40	0.915	−1.713	0.094
14	3.18	0.777	3.50	0.895	−3.383*	0.002
15	3.62	0.716	3.71	0.874	−1.796	0.079
16	3.69	0.793	3.84	0.763	−2.721**	0.009
17	3.76	0.679	3.93	0.668	−2.803**	0.008
18	3.56	0.693	3.78	0.767	−3.017**	0.004
19	3.49	0.787	3.64	0.842	−2.145*	0.037
20	3.44	0.841	3.52	0.751	−1.832	0.074
21	3.84	0.673	4.00	0.726	−2.432*	0.019
22	4.04	0.706	4.00	0.747	−1.000	0.323
23	3.91	0.793	3.93	0.763	−1.242	0.221

$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

4. Conclusion

Because an enormous amount of aircraft engine data is collected from numerous sensors, students need to learn how to analyze the data efficiently and find and solve problems for the effective maintenance of aircraft. Thus, we investigated whether using PBL improved students' ability when teaching the PT6A starting system and HIS, using sensor data to examine the combustion chamber, vane rings, compressor turbine disk, power turbine, temperature sensing system, and shroud segment. In this study, a questionnaire survey was carried out to find how PBL helped students in acquiring professional knowledge as well as in problem organization, problem analysis, problem description, problem solving, and teamwork. The findings showed that students improved their ability in general, especially in data collection and analysis, which was validated by the survey and paired-sample t-tests of the scores before and after PBL. Students were able to fully understand the operation and function of the engine system and had improved understanding of problems based on sensor data after participating in PBL. Education using sensor data and PBL can contribute to developing teaching methods for aircraft engine systems as it enhances problem-defining and problem-solving abilities. From the guidance, analysis, and discussion of problems in PBL, students became better at understanding the principles of aircraft systems and the contents of their textbooks. In the future, by using more sensor data to realize virtual reality (VR) and augmented reality (AR), the effect of PBL combined with such technologies will be studied.

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