Examining Grade 11 students’ existing ideas of engineering design process of fluid and Bernoulli’s principle through Predict-Observe-Explain (POE)

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Abstract. This study aimed to examine Grade 11 students’ existing ideas of the engineering design process on the problem based on fluid and Bernoulli’s principle unit through predict-observe-explain (POE). To promote high school students’ engineering literacy. Participants included 36 Grade 11 students who were studying in Khon Kaen University Demonstration Secondary School (Suksasart), organized into 7 groups. Methodology regarded interpretive paradigm. The Hynes et.al. (2011) framework of the engineering design process (EDP) was applied as the reference of students’ existing ideas of the engineering design process (EDP) consists of 9 steps including 1) identify need or problem, 2) research need or problem, 3) develop possible solutions, 4) select the best possible solution, 5) construct a prototype, 6) test and evaluate solution, 7) communicate the solution, 8) redesign and 9) completion decision. The question to start with “how the airplane can fly in the air” was the main problem, provided students to design possible solutions. The findings indicated that students cooperative learning to apply Bernoulli’s principles to solve the problem was interpreted to clarify students’ existing ideas of the engineering design process. The paper may have implications for STEM education teaching and learning.

Keywords: Engineering Process design, STEM education, Fluid and Bernoulli’s principal, POE

1. Introduction

Humans have continually developed scientific knowledge about the natural world. With scientific inquiry under scientific ideas that can change when new better information is discovered. Therefore it is more important than a learning management that gives particular importance to knowledge. Predictive-observation-explanatory learning management (Predict – Observe – Explain, POE) is another form of learning management based on constructivist concepts. (Constructivism), which has 3 steps, which are the stages of prediction (predict, P) are the steps in which the student must predict how the experiment or situation will result, however, by observing Fundamental knowledge and experience Which is forward-looking based on scientific skills, such as hypothesis and forecasting skills Observing (O) is the process that the students have to do experiments. Prediction and observation could foster students to find answers about experiments, activities, and problem situations. In this step, students require to use experimental skills such as observation, measurement and forecasting skills. And, the step of explain is the process of comparing the students’ predictions with the experimental results. In this step, students require scientific skills including data interpretation skills and draw conclusions. Students need the data interpretation skills to explain why the answers
given by the experiment are the same or different from predictions. In this process, the learners came to conflicts between what they predicted and what they found the results of the experiment. This allows students to revise their ideas of explanation which a theory could be constructed based on their experiences gained from the experiment [1], [18], [22], [23], [24].

Science is driven by human curiosity while engineering is driven by human needs and problem-solving criteria. Children have natural curiosity about the world around them, especially science. They enjoy doing experiments in science and exploring new things. They may want to observe or measure things around them. Such practical activities are motivating and engaging, especially if there are strong collaborative elements. Working with a classmate ensures that there is someone to share ideas, acquire knowledge, and also promote social development as well as emotional growth. Students’ curiosity is fuelled when they find out enough to know that there are still questions to ask and things to investigate [2].

For Science instructional management, the students should be focused on knowledge and understanding in boundary, nature, and limitation of science, components of science as the content collecting facts, concepts, hypotheses, principles, theories, rules of science until it could be utilized as well as the technique in searching for science process knowledge, obtaining understanding and awareness of the importance of science toward participation in society so that the students would be developed for higher-order thinking, problem-solving ability, communication and decision making, scientific attitude [3].

Collectively, the six position papers [4], [5], [6], [7], [8], [9] provide an intriguing foundation for answering these questions and forming a framework for engineering design in high school STEM courses. This synthesis paper discusses the most pervasive themes of the papers and provides a narrative for answering the question, “What are the requirements for a good engineering design challenge?” The following emergent themes provide some guidance to finding answers for that question: engineering design in the science curriculum; assessing the engineering design experience; sequencing the engineering design experiences; and choosing engineering design challenges. By addressing these areas of contention, the education community can begin to lay the curricular and pedagogical groundwork needed to provide successful engineering experiences for high school students [10].

Most educators agree with the idea of teaching engineering design to high school students has merit. Engineering education in high school promotes engineering “habits of mind” [4] and critical thinking skills, as well as providing a platform for the application of math and science [6]. Recently, there seems to be a push by educators for the integration of an engineering design framework into the science setting [9].

Hynes et al. suggest that infusing engineering design into the high school science curriculum would satisfy the need to provide engineering design with a set of standards that would serve as guiding principles for the competencies, skills, and knowledge that all students should develop. This push for engineering design in the science curriculum seems logical but comes without a convincing argument from the authors. It is true that science courses at the high school level, such as physics, provide an excellent milieu for the introduction of design problems [10].

What the conceptions of STEM education should be provided for teachers? It found that descriptions of what comprises STEM content and practices and what STEM conceptions look like range in the literature, especially conceptions of STEM education [1]. However, there are three consensus issues of discussion about STEM education including (a) instructionally (b) as a set of integrated or interconnected disciplines, or (c) as more dependent on the stakeholders or context in which it is viewed or conceptualized. For this study, we will hold Moore et.al. [11] definition of STEM education for enhancing teachers. They define it as “the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies.” To them, five characteristics distinguish integrated STEM instruction from other teacher pedagogy: (a) the content and practices of one or more anchor science and mathematics disciplines define some of the primary learning goals; (b) the integrator is the engineering practices and engineering design of technologies as the context; (c) the engineering design or engineering practices related to relevant technologies requires the use of scientific and mathematical concepts through design justification; (d) the development of 21st century skills is emphasized; and (e) the context of instruction requires solving
a real-world problem or task through teamwork. This conceptualization of STEM is grounded in learning research [17], [19], [20], [21].

Thailand Office of Basic Education Commission (OBEC) has pushed in-service teachers to develop his or her competence of organizing STEM education instruction. The OBEC STEM in-service teacher professional development project called STEM smart trainer team organized the workshop across the nation in order to enhance teachers to understand the concept of STEM education and fundamental ideas of utilizing STEM instructional approaches in their classroom. The STEM smart trainer team project enhanced teachers to provide STEM learning activities through engineering design process (EDP) [17], [19].

In this physics subject, Grade 11 Student will learn on Fluid and Bernoulli's principle unit, Bernoulli’s principle relates the pressure of a fluid to its elevation and its speed. Bernoulli’s equation can be used to approximate these parameters in water, air or any fluid that has very low viscosity. Students can use the associated activity to learn about the relationships between the components of the Bernoulli equation through real-life engineering examples and practice problems [15].

This paper aimed to clarify the developing STEM education learning activities to promote the concept of engineering design process. The learning activities were developed for Grade 11 students who will study in the subject of Physics of Demonstration School, Khon Kaen University, Thailand.

2. Target group
The participants were 36 Grade 11 students of Demonstration School, Khon Kaen University Khon Kaen, and Thailand, organized into 7 groups.

3. Methodology
This research was used predict-observe-explain (POE) as the way to promote learning activity by interpretive consideration from interview students' ideas during activities and analysis data from sheet on Google drives of students. The question "how the plane can fly in the air" was the main problem to promote the students' ideas of the engineering design process on the framework of Hynes et.al. [6].

3.1 Research Framework
1) Stem Education and Engineering Design
The combination of the concept of engineering design and learning of Science, Technology, and Mathematics is unique to STEM learning organizations. As students attempt to learn, understand and practice skills in Science, Technology, and Mathematics, they have an opportunity to apply the knowledge gained to design a product or a method to meet their daily life problem-solving needs [12]. The Engineering Design Process (EDP) refers to organizing ideas to improve decision making in order to develop high-quality solutions and/or products to problems. The main objectives EDP is 1) students become engineers, meaning that teachers need to listen to students, and 2) classroom environment need to change properly to enable learning through the EDP. Specifically, skills and abilities associated with engineering design for high school student consist of nine stages according to including (1) identify need or problem, (2) research the need or problem, (3) develop possible solution(s), (4) select the best possible solution, (5) construct a prototype, (6) test and evaluate the solution, (7) communicate the solution, (8) redesign and (9) completion decision (see Figure 1) [13], [16].

Throughout this process, students repetitively assess and challenge their ideas by repeating steps every now and then, even restarting from the beginning. Frequently, the imaginative ideas emerged from overlooking the flaws, or a different approach may become apparent through work on the challenge [13], [14].
2) Predict–Observe–Explain (POE)

The predict–observe–explain (POE) procedure as an efficient strategy for eliciting and promoting discussion of students’ science conceptions. This strategy involves students predicting the outcome of a demonstration, committing themselves to a possible reason for their prediction, observing the demonstration, and finally explaining any discrepancies between their prediction and observation. Whether used individually or in collaboration with other students, POE tasks can help students explore and justify their own individual ideas, especially in the prediction and reasoning stage. If the observation phase of the POE task provides some conflict with the students’ earlier predictions, reconstructions and revision of initial ideas are possible [1].

Table 1: learning activities for 6 periods of lesson

| Step     | Learning activities                                                                                                                                 |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Predict  | Ask the students to predict how the plane can fly in the air and why they think about that, what scientific principles were supported. What students have done and corresponds to the engineering design process (EDP). |
| Observe  | Students have to build a plane model for the evaluation of their prediction and record what they have observe from these activities. What students have done and corresponded to the engineering design process (EDP). |
| Explain  | After that students have committed their explanation and present their ideas in the classroom. What students have done and corresponded to the engineering design process (EDP). |

4. Data Collection and Analysis

4.1 Data Collection

1) Interview students’ ideas during activities.
2) Data from activity steps of students on Google drives, the teacher asked students to record on google drive.
3) The plane model of students.

4.2 Data Analysis

To start, the teacher opens a video about the takeoff plane for students to watch. And ask students “how the plane can fly in the air”. The second, students work together to build the plane model and
lets it float by using wind from the electric fan. Then define the problem and conditions for the students.

1) The students together design and built a plane model, can fly in the air with the wind from the fan.
2) The students can used materials to build a plane model, depends on them.
3) The students have to present concepts and principles that can be used for the problem-solving process.

![Figure 2. Takeoff plane (https://www.youtube.com/watch?v=6j_Nf1h40wA).](https://www.youtube.com/watch?v=6j_Nf1h40wA)

4.2.1 Steps for data analysis through predict: the students to predict how the plane can fly in the air and why they think about that, what scientific principles were supported.

![Figure 3. Problem and conditions.](image)

• All of the groups knew the problem based on situations from the teacher define which corresponds to step 1, the Identify problem of engineer design process (EDP).
Table 2. Showed students have brainstormed and discussed.

Data analysis

Figure 4. Example for search of students.  Figure 5. Discuss to possible solutions.

Learning activities

All of the groups have searched scientific concept to design the plane model, brainstormed and discussed each other in groups to find the best possible materials.

Examples: Students interviewed by divided into 2 concepts.

Concept 1, materials for use: It requires lightweight materials and strong. All student groups choose to use foam and flute board to build the plane model.

Concept 2, how to make the plane model can fly, float up and down. The concepts of students have consisted of 3 ideas.

1) Some groups have drilled holes in both wings of the plane model and use a small string to pierce through the hole the plane model. When the wind hits the wing the plane model can float it up to follow figure 6.

2) Other groups have drilled holes in both wings of the plane model. Then use steel as a pair of columns for the plane to slide up and down. When the wind hits the wing the plane model can float it up to follow figure 7.

3) They have built the wings of the plane model curved surface, the shape above the wings to make it curved.

Figure 6. Some groups have drilled holes in both wings of the plane model. (Teacher sketch from students interviewing)

Figure 7. Other groups have drilled holes in both wings of the plane model. (Teacher sketch from students interviewing)

• This result showed which corresponds to step 2, research of engineer design process (EDP) and step 3, possible solutions of engineer design process (EDP).
Table 3. Showed students have applied scientific principles to their work.

Data analysis

Figure 8. Scientific principles of students to support (http://www.unc.edu/~threveni/sailing/lift.html).

Learning activities

- Students have applied scientific principles and analysis to guide the creation of the plane model which corresponds to step 4, select the best solution of engineer design process (EDP).

The principles of Bernulli: In fluid dynamics, Bernoulli's principle states that for an inviscid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

- All of the groups quote to the principles of Bernulli in the design of the plane mode. Have to make the plane wings unevenly curved, the shape above the wings will make it curve. The lower surface will make a straight, smooth surface. So that airflow above the wing surface is faster than the bottom of the wing, then the force can lift the plane to float to followed figure 8.

4.2.2 Steps for data analysis through observed: Students have to build a plane model for the evaluation of their prediction and record what they can observe from activities.

Table 4. The result of process to build the plane model of student group #1.

Data analysis

Figure 9. The process to build the plane model of student group #1.

Learning activities

Group #1: The process to build the plane model of student follow figure 9.

- Step 1: They start to design the plane model that can be possible, the shape above of the wings curved more than under the wings.
- Step 2: They have to cut the foam for makes the plane model according to their design and drilled holes in both wings of the plane model.
- Step 3: They have taken various parts complementary to the plane model.
Table 5. The result of process to build the plane model of student group #2.

Data analysis

Figuer 10. The process to build the plane model of student group #2.

Learning activities

Group #2: The process to build the plane model of student follow figure 10.
• Step 1: They start to design the plane model that can be possible. They used the flute board to make a wing, above the wing slightly curved and the body model looks like box shape.
• Step 2: They have to cut the flute board for makes the plane model according to their design and drilled holes in both wings of the plane model and use a small string to pierce through the hole the plane model.
• Step 3: They have taken various parts complementary to the plane model.

Table 6. The result of process to build the plane model of student group #3.

Data analysis

Figuer 11. The process to build the plane model of student group #3.

Learning activities

Group #3: The process to build the plane model of student follow figure 11.
Step 1: They start to design the plane model that can be possible. They used the foam to make a wing and body. The shape above the wing curved more than under the wing, the wing size was 5x70 cm, the length was 53 cm.
Step 2: They have to cut the foam for makes the plane model according to their design.
Step 3: They have taken various parts complementary to the plane model and paint color on the plane model.
Table 7. The result of process to build the plane model of student group #4.

| Learning activities | Group #4: The process to build the plane model of student follow figure 12. |
|--------------------|--------------------------------------------------------------------------|
| Step 1:            | They start to design the plane model that can be possible. They used the foam to make a wing, above curved slightly. The part of the body model looks like an airplane. |
| Step 2:            | They have to cut the foam for makes the plane model according to their design and drilled holes in both wings of the plane model and use a small string to pierce through the hole the plane model. |
| Step 3:            | They have taken various parts complementary to the plane model and paint color on the plane model. |

Table 8. The result of process to build the plane model of student group #5.

| Learning activities | Group #5: The process to build the plane model of student follow figure 13. |
|--------------------|--------------------------------------------------------------------------|
| Step 1:            | They start to design the plane model that can be possible, use foam to make both of wings, above curved slightly. They have to make part of the body model looks like cockpit of an airplane. |
| Step 2:            | They have to cut the foam for makes the plane model according to their design and drilled holes in both wings of the plane model and use a small string to pierce through the hole the plane model. |
| Step 3:            | They have taken various parts complementary to the plane model and paint color on the plane model. |
Table 9. The result of process to build the plane model of student group #6.

Data analysis

![Images of the process to build the plane model of student group #6.](image1)

**Figure 14.** The process to build the plane model of student group #6.

**Learning activities**

Group #6: The process to build the plane model of student follow figure 14.

Step 1: This group starts to design the plane model differently from other groups. They cut the flute board to make a model after that to make a prototype the plane model by foam.

Step 2: They have to cut the foam for making the plane model according to their design.

Step 3: They have taken various parts complementary to the plane model and paint color on the plane model.

Table 10. The result of process to build the plane model of student group #7.

Data analysis

![Images of the process to build the plane model of student group #7.](image2)

**Figure 15.** The process to build the plane model of student group #7.

**Learning activities**

Group #7: The process to build the plane model of student follow figure 15.

• Step 1: They start to design the plane model that can be possible. They used the flute board to make a wing, above curved slightly.

• Step 2: They have to cut the flute board for making the plane model according to their design and drilled holes in both wings of the plane model and use a small string to pierce through the hole the plane model. They make a tripod for the plane to slide up and down.

• Step 3: They have taken various parts complementary to the plane model.

• This result showed the process to build the plane model of all groups which corresponds to step 5, construct a prototype of engineer design process (EDP).
Table 11. Test and evaluate the solution of students.

| Data analysis |
|---------------|
| ![Image](image1.png) |

**Figure 16.** Examples test and evaluate solution of students.

### Learning activities
- All of the groups test their plane model for the float by used an electric fan which corresponds to step 6, test and evaluate solution of engineer design process (EDP) to follow figure 16.

#### 4.2.3 Steps for data analysis through the step of explain

Table 12. The presentation of students.

| Data analysis |
|---------------|
| ![Image](image2.png) |

**Figure 17.** Example students have presents their ideas and process used to solve problems.

### Learning activities
- Analysis protocol on sheet of student: Main concept of all groups. They used Bernoulli’s principle to describe the lifting force. The plane model can achieve lift because of the shape of its wings. When the air flows faster over the top of the wing and slower underneath. Fast-moving air equals low air pressure while slow-moving air equals high air pressure. The high air pressure underneath the wings will, therefore, push the aircraft up through the lower air pressure.

- All groups of students present their ideas and process of creating a plane model including scientific principles that were used to solve problems which corresponds to step 7, communicate the solution of engineer design process (EDP).

- When students found some problem they have to modify the plane model and try again, which corresponds to step 8, redesign of engineer design process (EDP). Example: The way to improve the plane model of student was optimized into 3 main ideas:
  - Method 1: reduced the friction of the rope attached to the wing
  - Method 2: adjusting the shape of wings more curvy.
  - Method 3: improves the plane model the least weight.

- All groups of students decided and present the best plane model, which corresponds to step 9, completion decision of engineer design process (EDP). It is seen that students have nine engineering processes that appear in this activity.
5. Conclusion
This research starts with the question "how the plane can fly in the air" for challenge students in the classroom to search scientific principles that were used to solve problems. After that, they were built as a plane model under the conditions specified through the predict-observe-explain (POE). The finding was showed this activity promotes students cooperative learning to apply Bernoulli's principles to solve the problem through the engineer design process 9 steps on the framework of Hynes et.al. (2011) including 1) identify need or problem, 2) research need or problem, 3) develop possible solutions, 4) select the best possible solution, 5) construct a prototype, 6) test and evaluate solution, 7) communicate the solution, 8) redesign and 9) completion decision. The students have to practice their prediction of what will happen on the problem, after that the student take action to solve the problem, finally, they have committed their explanations and present their ideas in the classroom. They have received knowledge of STEM studies, the students’ necessary skills for 21st century.

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