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Enhancing Grade 11 Students' Learning and Innovation Skills in the STS Electric Unit

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Abstract. The objective of this study is to investigate grade 11 students' learning and innovation skills by using science technology society approach. The participants included 35 Grade 11 students, Chiangyuenpittayakhom School, Chiangyuen, Maha Sarakham Province. The STS electric unit was developed by aligned Thailand content standards of electric and electric power regarding on Yuenyong (2006)'s science technology society approach. Methodology regarded interpretive paradigm. Students' learning and innovation skills were examined when students studied in the STS electric unit. The tools of interpretation included the learning and innovation skills assessment forms (LISA) and the unstructured interview. Data analysis students' tasks were evaluated and categorized by LISA forms. Then, participant observation, student work sheets and unstructured interview interpretation supported what researchers' understanding of student learning and innovation skills. The students' learning and innovation skills were clarified as three aspects with 9 indicators. These included 1) critical thinking and problem solving with 4 indicators, 2) communication and collaboration with 2 indicators, and 3) creativity and innovation with 3 indicators. The findings revealed that there were different levels of students' competency on learning and innovation skills of the 21st century. Two groups of students' prototypes (circuit breaker and control breaker) could be interpreted as very good level of students' competency on learning and innovation skills of the 21st century. Students, who developed prototypes of safe electric wire, could be interpreted as level of good. Other two groups of students, who developed prototypes of electric wire protection and guideline poster for short circuit prevention, could be interpreted as level of fair. The paper also highlights what students developed prototypes of their groups as a solution.
Keywords: electric, STS, STEM, learning and innovation skills

1. Introduction

Regarding on the rapid changing society, globalization, and growth of technology in the 21st century; information has become potentially important for human living throughout the world. This phenomenon expands into the educational perspectives. Learners are required to be equipped with not only academic knowledge but also the skills of technology and innovation. One of international movement embracing the need for the development of student 21st Century skills is the propagation of inclusive STEM high schools, schools that serve all students regardless of prior academic achievement. STEM education promotes student research experiences by using inquiry based

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curricular models to scaffold independent learning and encourage personal responsibility. The goal for STEM education to facilitate this type of student-centered learning is to build students' 21st Century skills (Sutaphan and Yuenyong, 2019). In an attempt to clearly define the skills, content knowledge and literacies that students would need to be successful in their future endeavors, the Partnership for 21st Century Learning (P21; 2016) created a framework that includes (a) life and career skills; (b) learning and innovation skills; (c) information, media, and technology skills; and (d) key subjects. The first three parts of the framework, (a) life and career skills, (b) learning and innovation skills, and (c) information, media, and technology skills, describe proficiencies or literacies students should develop and can be integrated and developed in any academic lesson. The fourth piece, key subjects, suggests 21st Century interdisciplinary themes or content to engage students in authentic study (Partnership for 21st Century Learning, 2016).

Thailand education is a major drive to develop human resources which means to overall country development. The key feature of Thailand education preparing for 21st century is about learning and innovation skills. According to Thailand Ministry of Education (2008), Thailand's education policy aim to enhance students' learning with the practical experience of the 21st innovation skills in order to optimize the endless information available globally to improve living conditions while holding the values of environmental and cultural conservation. In order to provide some framework of this study, the P21 framework of learning and innovation skills will be clarified.

The P21 provided the learning and innovation skills as the prepared for a more and more complex life and work environments in the 21st century. The components of the learning and innovation skills include creativity and innovation, critical thinking and problem solving, and communication and collaboration. These are complex components of essential to prepare students for the future. The creativity and innovation could be viewed as creative thinking for developing innovation. The creativity and innovation, therefore, consists of thinking creatively, work creatively with others, and implement innovations. Critical thinking and problem solving could be viewed as critical thinking for problem solving. The elements of critical thinking and problem solving, therefore, consist of reason effectively, use system thinking, make judgments and decisions, and solve problems. Communication and collaboration is a skill that allows students to learn through problem solving and developing innovation. Therefore, communication and collaboration refers to 1) communicate clearly in a variety of forms and contexts, a range of purposes, and diverse environments, and 2) collaborate with others to work effectively and respectfully with diverse teams, to exercise flexibility and willingness, and to assume shared responsibility (Partnership for 21st Century Learning, 2016).

In order to enhance students' learning and innovation skills for surviving in 21st century, the literatures suggested that real-world problem solving provided students to develop the prepared skills for the future. Real-world problem solving is characterized by students working to solve problems that have no current solution and where the students can implement their own approach. When solving a real-world problem, students work to identify the problem, propose a solution for a specific client, test the solution, and share their ideas. The design aspect of the process encourages students to be creative and learn from failures. When using real-world problem solving, students develop knowledge in a meaningful way, must regulate their cognition and behavior in a way to reach their goals, and gain experience defending their choices through evidence and effective communication skills. Teachers can develop real-world problem solving skills in their students by modeling inquiry after research actual scientist are involved in, using databases with real life data, and evaluating evidence from current events. Designing real-world problem scenarios for the classroom provide a framework by which students can engage in 21st Century learning and can help to encourage a more

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positive attitude towards STEM careers (Narjaikaew and Yuenyong, 2009; Ladachart and Yuenyong, 2017; Yuenyong, 2019).

In Thailand, Science-Technology-Social (STS) education widely adopted in class using the issues-based approach as suggested in previous studies (Wongsila and Yuenyong, 2019; Nongkhunsarn et.al., 2019; Tupsai et.al., 2019). Those studies adopted 5 stages of Yuenyong (2006) STS teaching strategy to design learning activities for enhancing students to find solutions of technological and societal issues. The 5 stages consist of (1) identification of social issues, (2) identification of potential solution, (3) need for knowledge, (4) decision making, and (5) socialization. Identification of social issue stage is to stimulate students to be aware of social problems that caused by scientific and technological issues and they are responsible to solve the problems. Identification of potential solution stage is to allow students to understand the current issues more deeply to seek solutions. Need for knowledge stage is to allow students to seek information for the solutions which can be pursued by various techniques (i.e. experiment, online searching. Decision –making stage is to allow students to apply information in their solution process and present their ideas in the form of project. Socialization stage is to allow student implement the solution in the society and get reflection for revising their solutions.

The lesson learned from those STS practices provided some good examples of project- and problems-based teaching and learning for real world problem solving. The STS support teachers to develop learners' skills for learning and innovation skills. The STS implementation in Thailand developed students' critical thinking, creative thinking, decision making and problem solving (Chitnork and Yuenyong, 2018; Yuenyong, 2017). There were many STS studies in Thailand that showed how student practicing knowledge for real world problem solving. For example, Wongsila and Yuenyong (2019) brought the issues of genetics and DNA technology into the STS biology classroom which enhanced students' critical thinking and problem solving. This research showed that the STS unit enhanced students to develop key feature of learning and innovation skills including reasoning effectively, using systems thinking, making judgments and decisions, and solving problems for the issue of growing GMO plant in Thailand. Another example, Seattha et. al. (2015) showed that students could apply the knowledge of projectile and motion in mathematical calculation to design the plastic bottle rocket and safe road project. Furthermore, practical knowledge (i.e. electricity) has been more highlighted in the innovative teaching which helps students to clearly understand and adopt it in their real life. This fundamental knowledge should be used to further broaden students' imagination and learning in the higher level, for example, how to prevent electric accidents and how to reduce the electricity use. Indeed, the electricity is important for people's living; however, its teaching content is complex (Seattha et.al., 2015; Ngaewkoodrua and Yuenyong, 2018).

To enhance students' learning and innovation skills, the energy is a concept that could allow students to tangible design innovation as a solution because energy related to everyday life and human needs. In particular, electric form of energy is fundamental knowledge practicing in many students' science projects (Yuenyong, 2017). The STS electric unit, therefore, probably provide learning environment for enhance students' learning and innovation skills. Consequently, this study provided the STS electric and power unit for Grade 11 students in order to develop their performances in creativity and innovation, critical thinking and problem solving, and communication and collaboration that represented their competency in feature of the 21st century learning and innovation.

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2. Methodology

Methodology regarded interpretive paradigm. The research aimed to interpret students' learning and innovation when they were participating in the STS electric and power unit. Students' learning and innovation could be drawn up through the students' creativity and innovation, critical thinking and problem solving, and communication and collaboration in order to draw students' learning and innovation.

2.1 Participants

Participants included 32 Grade 11 students who were studying in Chiangyuenpittayakhom School, Chiangyuen, Maha Sarakham Province, the 2nd semester in the academic year 2018.

2.2 Intervention of STS energy and power unit

The STS energy and power unit was developed aligning to Thailand basic education curriculum (B.E. 2551). The unit provided the social and technological issues related to electricity and power through the five stages of Yuenyong (2006) STS in order to engage students to practice knowledge for problem solving. According to Yuenyong (2006), the five stages included 1) identification of social issues, 2) identification of potential solutions, 3) need for knowledge, 4) decision-making, and 5) socialization. Based on five stages, the unit provided 2 lesson plans (4 hours) and 2 hours outside classroom. And, to scaffold students' engineering design, the lesson plans integrated the Hynes et al (2011)'s engineering design process. Hynes et al (2011) framework included 1) identify need for problem, research need or problem, 3) develop possible solutions, 4) select best possible solution, 5) construct a prototype, 6) test and evaluate solution, 7) communicate the solution, resign, and 9) complete decision. The Hynes et al (2011)'s engineering design process will regulate students to seek more information during the need for knowledge in the 3rd stage and improves their decision-making process in the 4th stage of Yuenyong (2006)'s approach more effectively as explained below.

1) Identification of social issues is the stage that the teacher encourages students to identify the problems regarding on social issues. The situation of fire accidents occurred in a community was presented to the class. Then, students identified the problems (e.g. what is the cause of the short circuit?). These problems required student applying scientific knowledge and others for developing solutions.

2) Identification of potential solution is the stage that students check their existing ideas and what they need for developing solutions. Students may plan how to find the possible ways to find the certain answers. They searched some guidelines, methods, or inventions that reduce short circuit protection. They listed their prior knowledge that related to the problems. And, they also searched for some knowledge about how much of amount of power safety used for any electrical devices, how amount of use power in each device effect to the short circuit, what science content knowledge may relate to design the electrical devices, or how to design the short circuit protection devices. Then, students shared these ideas among other groups. This activity allowed teacher to suggest students to do some activities in order to foster students to make sense about electricity and power. Then, the learning activities in need for knowledge stage were introduced to students. Teachers summarized the relevant knowledge of electricity and power related to the cause of short circuit, such as electrical equipment and appliances, and the excessive amount of electricity or electricity usage.

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3) Need for knowledge is the stage of physics learning activities. These activities included doing experiments about the relation between current, voltages, and resistances in a circuit; explanation about the relation of electricity and its power from the definition and the equation; solving electricity and power exercises, and explanation about cause of electric shock and short circuit. And, teacher provided some suggestions to students in order to scaffold them to develop some methods, design, or equipment that would be needed for developing short circuit protection devices.

4) Decision making stage enhanced students to apply their knowledge for developing prototypes or products of equipment needed in the protection of short circuit. In this stage students must consider whether the design and device invention are possible or not, what are the benefits and disadvantages. The Hynes et al. (2011) engineering design process (EDP) was introduced to students in order to regulate their solving problem for developing prototypes or products concerning on EDP.

5) Socialization stage provided students to review their concepts in solving the problems by presenting how they decision was made to design the short circuit protection devices. Then, students have to present what and how develop the prototype or products about short circuit protection devices regarding on Hynes et al. (2011) EDP. Students, therefore, presented their developing ideas through following 7 steps - (a) Identification of Problem or Need, (b) Data collection, (c) Method selection, (d) Design and Practice process, (e) Testing, (f) Revision, and (g) Evaluation. During this stage, students can exchange or recheck their ideas in order to optimize their prototypes of the short circuit protection devices.

2.3 Tools for interpretation of students' learning and innovation skills for the 21st century

According to P21, the components of the learning and innovation skills in the 21st century include creativity and innovation, critical thinking and problem solving, and communication and collaboration. The complex components of the learning and innovation skills will be interpreted through various tools. The tools of interpretation included the learning and innovation skills assessment forms (LISA), and the unstructured interview.

2.3.1 The learning and innovation skills assessment forms (LISA)

The learning and innovation skills assessment forms (LISA) was developed by Jaikla (2018). The LISA could be used to examine students' behaviors during students on class and on tasks. The LISA provided the criteria observation LISA (O-LISA) form and score rubric of student prototype assessment for learning and innovation skills (P-LISA).

1) Observation LISA (O-LISA) form provided pool of indicators for the learning and innovation skills in the 21st century. These indicators included 1) four indicators of critical-thinking and problem-solving skills, 2) two indicators of communication and collaboration skills, and 3) three indicators of creativity and innovation skills. The indicators and items were provided in the Table 1. According to the table 1, Jaikla (2018) developed the LISA through expert panel to weight the component of learning and innovation skills. Therefore, each component of LISA was provided the different score weight. However, in each component, each indicator has the same weight score of each indicator so that it can be equally used to identify the average score between the two research tools. The observers have to bring the LISA form to evaluate students' behaviors for certain components of the learning and innovation skills in the 21st century. To provide the creditability, students' learning and innovation skills should be assessed at least two examiners. Then, the average score can be converted into the percentage reflecting the quality of each component of students' learning skills and innovation of the 21st century. For the evaluators, the O-LISA is used to check whether students reflected with desired skills or not. The evaluators have to rate the 1 point or 0 point for the level of students' behavior that reflect each component of learning skills

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and innovations of the 21st century. The 1 point refers that students reflect the desired skills. And, the 0 point refers that has no evidence of desired skills. Then, the scores obtained from both evaluators' observation were divided by the number of the lists of indicators of behavior marked as 1, then multiplied with the weight score of each indicator. Finally the total of all indicators' score is will be used to determine the degree of behavior that reflected the components of learning and innovation skills of the 21st century. The level of each component ranged from poor, fair, good, and very good as presented in the table 3.

Table 1: Indicators and score weight of students' behaviors representing for learning and innovation skills (Adapted from Jaikla, 2018)

Components of Learning and Innovation skills of the 21st Century	Indicator	List of students' behaviors	No. of items	Score weight of Indicator	Overall Score Weight of Indicators
Critical-thinking and problem-solving skills	Students have reasoning skills	1) Students can express reasons among group members.	3	2.830	8.492
		2) Students can answers the questions or scientific facts			
		3) Students can show ideas to explain the issues.			
	Students have systematic thinking skills	4) Students can point out the details or causes of the issues.	3	2.697	8.091
		5) Students can classify issues.			
		6) Students can point out the relationship among different point of issues.			
	Students have systematic decision-making process.	7) Students can select the appropriate methods for seeking solutions.	6	1.585	9.508
		8) Students can refer the sources of information.			
		9) Students can identify advantages and disadvantages of each method of the solutions.			
		10) Students can prioritize the importance of each point.			
		11) Students can identify the linkage of knowledge to seek conclusion.			
		12) Students can use the linkage of knowledge to plan for the solutions.			
	Students have problem-solving skills	13) Students can identify what to be answered.	4	2.280	9.118
		14) Students can identify the cause of issues.			
		15) Students can identify several methods to select one best solution.			
		16) Students can solve problems.			

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Table 1: (Continued)

Components of Learning and Innovation skills of the 21st Century	Indicator	List of students' behaviors	No. of items	Score weight of Indicator	Overall Score Weight of Indicators
Communication and collaboration skills	Students have communication skills.	17) Students can communicate in a verbal and written manner to persuade others to follow their ideas.	5	3.725	18.623
		18) Students can communicate with other non-verbal manners.			
		19) Students can apply technology in communication with others.			
		20) Students can use technology to explain more detailed information to others.			
		21) Students can communicate with others about the situations and issues.			
	Students have collaboration skills to work with others.	22) Students can plan the group work effectively.	9	1.867	16.807
		23) Students can meet the deadline as planned.			
		24) Students are active to work in group.			
		25) Students can act as leader and team supporter.			
		26) Students listen to each other's ideas.			
		27) Student show good collaborate to other and come up with good results.			
		28) Students discuss all members' ideas to construct group work.			
		29) Students eagerly work as assigned.			
		30) Students understand their team roles and meet the plan.			
Creativity and innovative skills	Students have creative-thinking skills.	31) Students show new ideas.	4	2.386	9.545
		32) Students show new ideas from what they have learnt to create new invention.			
		33) Students identify their weakness and strengths.			
		34) Students try to improve their performance.			
Creativity and innovative skills	Students have creativity and imagination when working with others.	35) Students express their ideas with others.	4	2.660	10.637
		36) Students listen to others' new ideas.			
		37) Students act as a leader gathering ideas to construct group work's plan			
		38) Students learn to improve their mistake for better performance.			

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Table 1: (Continued)

Components of Learning and Innovation skills of the 21st Century	Indicator	List of students' behaviors	No. of items	Score weight of Indicator	Overall Score Weight of Indicators
	Students can apply knowledge into innovative invention.	39) Students learn to construct knowledge from that they have already learnt.	3	3.059	9.177
		40) Students seek new approaches to create greater work piece.			
		41) Students implement their new ideas until being able to create an invention.			

2) Student prototype assessment for learning and innovation skills (P-LISA) provided score rubric and score weight of indicators for each component of the learning and innovation skills in the 21st century. Two examiners evaluate students' developing prototype of the short circuit protection devices in order to assess student scores of learning and innovation skills. The P-LISA was used to evaluate students' worksheets and behaviors during students on tasks. Regarding on the P-LISA as the table 2, the examiners have to rate quality level for each indicator. The scoring rubric consists of 3 levels including good (3 points), fair (2 points), and poor (1 point). To calculate the score of each indicator, the average rating rubric score of two examiners will be multiplied by its score weight as provided in the table 2. Then, the total score of all components could be summed by score of each indicator. The total score will be interpreted into 4 levels of students' competence on learning and innovation skills as showed in the table 3. The level of each component ranged from poor, fair, good, and very good.

Table 2: Scoring rubric and score weight of each indicators of learning and innovation skills for evaluating students' developing prototypes (Adapted from Jaikla, 2018)

Components of Learning and Innovation skills	**Indicator**	**Quality Level**	**Score Weight of Indicator**	**Overall Score Weight of Indicators**
Critical-thinking and problem-solving skills	Students have reasoning skills.	Criteria for quality scoring in 3 levels: Good = 3 points Fair = 2 points Poor = 1 point	2.831	8.493
	Students have systematic thinking skills.		2.697	8.091
	Students have systematic decision-making process.		3.169	9.507
	Students have problem-solving skills.		3.039	9.117
Communication and collaboration skills	Students have communication skills.		6.207	18.621
	Students have collaboration skills to work with others.		5.602	16.806
Creativity and innovative skills	Students have creative-thinking skills.		3.182	9.546
	Students have creativity and imagination when working with others.		3.545	10.635
	Students can apply knowledge into innovative invention.		3.059	9.177

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Table 3 Criteria for levels of students' competence on learning and innovation skills

Score Range	Quality Level
100 - 80	Very good
79 - 70	Good
69 - 60	Fair
59 - 0	Poor

2.3.1 Unstructured interview

Unstructured interview was further probed after use O-LISA and P-LISA. The probing questions aimed to clarify what students' applying knowledge and dilemma for problem solving on the social and technological issue about developing the short circuit protection devices. The issues of students' knowledge and dilemma will be categorized and formed patterns for explanation of students' story of developing prototype. Their story could provide credibility, audit trailing of data collection and analysis, students' context of learning for transferability.

3. Results

It revealed that the intervention of STS energy and power unit allowed students could collaborate among students' group member to develop their solution for energy and power issue. Five groups of students' collaboration provided differently prototypes as solution. These included 1) pipe for wire protection group, 2) control breaker group, 3) guideline poster for short circuit protection group, 4) electric cable safety group, and 5) power socket safety group. Through students' developing their solution, it found that students' learning and innovation skills for the 21st century could be examined when the identified the problem, making decision for a solution, and develop their prototype through Hynes et al (2011)'s engineering design process. The data of O-LISA, P-LISA, and unstructured interview suggested us to interpret each group of students' competency in learning and innovation skills as provided in the table 4.

Table 4: Level of students' competency on learning and innovation skills of the 21st century

Group	**Components of students' learning and innovation skills of the 21st century**	**Average score of each indicator**	**Average score**	**Level of each indicator**	**Students' learning and innovation skills of the 21st century**
Electric wire protection	Critical-thinking and problem-solving skills	22.39	63.59	Fair	Fair
	Communication and collaboration skills	26.90	75.91	Good	
	Creativity and innovative skills	15.16	51.64	Poor	
Guideline poster for short circuit prevention	Critical-thinking and problem-solving skills	25.60	72.69	Good	Fair
	Communication and collaboration skills	29.06	82.02	Very good	
	Creativity and innovative skills	12.50	42.56	Poor	
Safety electric wire	Critical-thinking and problem-solving skills	25.63	72.80	Good	Good
	Communication and collaboration skills	30.93	87.29	Very good	
	Creativity and innovative skills	17.85	60.8	Fair	

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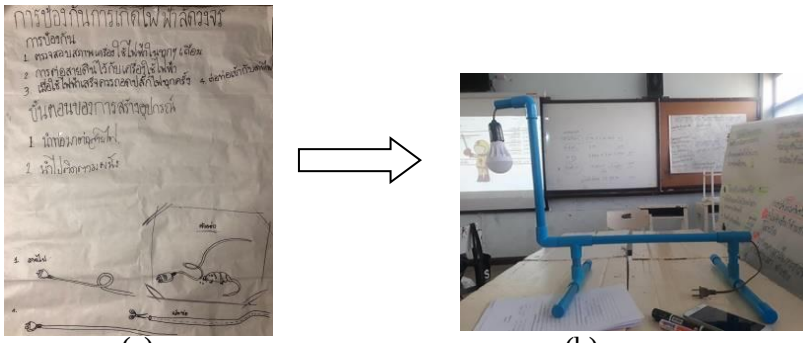
Table 4: (Cont')

Group	Components of students' learning and innovation skills of the 21st century	Average score of each indicator	Average score	Level of each indicator	Students' learning and innovation skills of the 21st century
Control breaker	Critical-thinking and problem-solving skills	29.99	85.15	Very good	Very good
	Communication and collaboration skills	30.00	84.65	Very good	
	Creativity and innovative skills	20.24	68.92	Fair	
Circuit breaker	Critical-thinking and problem-solving skills	31.40	89.17	Very good	Very good
	Communication and collaboration skills	31.40	88.61	Very good	
	Creativity and innovative skills	21.44	73.01	Good	

According to table 4, it showed that there were different levels of students' competency on learning and innovation skills of the 21st century. Two groups of students' prototypes (circuit breaker and control breaker) could be interpreted as very good level of students' competency on learning and innovation skills of the 21st century. Students, who developed prototypes of safe electric wire, could be interpreted as level of good. Other two groups of students, who developed prototypes of electric wire protection and guideline poster for short circuit prevention, could be interpreted as level of fair. Each group of students' developing prototypes will be discussed more details as following sections.

3.1 Student group of electrical wire protection was evaluated as fair level of competency on learning and innovation skills

Student group of electrical wire protection was evaluated as fair level of students' competency on learning and innovation skills of the 21st century. Students pointed out the key concepts of electrical wire protection pipe invention starting. This could be interpreted when they identified problems by asking question of "what and how should we do to prevent the mouse biting the wires?" The mouse biting the electrical wires would peel out insulator that could be one of the causes of electric shock. They came up with an idea of providing pipes to prevent the wire away from animals and water. On the way of their developing prototype, they learn how to optimize their design. Then, they could develop the innovation of pipes to prevent the electrical wires from water and animals. Some pictures of their developing ideas and revised prototype could be viewed as the figure 1.



(a) (b)

Figure 1 Students' developing ideas and revised prototype of electrical wire protection pipes

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The figure 1a showed how students drew up their ideas of solving problem to develop prototype regarding on the Hynes et al. (2011) engineering design process (EDP). They identified the problem about "how to prevent the mouse from biting the wire?", "how to prevent the circuit shock?". They developed ideas for their data collection via searching information for causes of electrical circuit shocks happen (e.g. overusing electricity, using torn cables or worn-out conditions, and leak on wires from the rat bite to seek). Students, then, applied their searched information to develop solutions to prevent the by inventing devices to protect electricity inside and outside the house. According to making decision, students selected materials and selected the most appropriate approach to construct prototype of devices to protect the wires. In design and implementation, students used PVC pipes to fit the wires that they wanted to prevent electric leakage from rats biting and water leaking in (figure 1b). In the testing, students mentioned that they had to do some experiment for trailing the device if the electric shock happens. The revision step, students rechecked the devices and modified the equipment by putting the stand above the ground, so it would not touch the water. Finally, the evaluation step, students evaluated their own device invention. They reflected that "the work piece can prevent the electrical wires from rats biting and prevent the wires from water to avoid electric shocks."

Regarding on students' performance, the researchers noted that the prototypes of electrical wire protection device could not fully function in the real setting. Some parts of the protection pipe were not practical. Therefore, it could not be concluded that the wire protection pipe could completely fix or prevent the cause of short circuit. Based on the above the description of students' performance, two examiners' evaluation on the O-LISA and P-LISA revealed that students could be interpreted for component of critical thinking and problem solving skills in fair level (average score 63.59%), component of communication and collaboration skills in good level (average score 75.91%), and component of creativity and innovative skills in poor level (average score 51.64%) as showed in the table 4. Based on these three components, the students' learning and innovation skills of the 21st century could be interpreted as fair level.

3.2 Student group of guideline poster for short circuit prevention as fair level of competency on learning and innovation skills

Students proposed the concept of a solution as developing some guidelines for short circuit protection when the learning activity asked them to identify the problem related to issues of preventing short circuits. Then, the need for knowledge stage allowed students to gain more knowledge about key concepts of short circuits and causes of short-circuits. To design the guidelines, their group members reviewed further about knowledge related short circuits and some examples of poster presentation. Their developing ideas of guideline poster for short circuit prevention started from brain storming for identifying problems and list possible solutions, and then finally published the completed guidelines in the social media as showed in the figure 2.

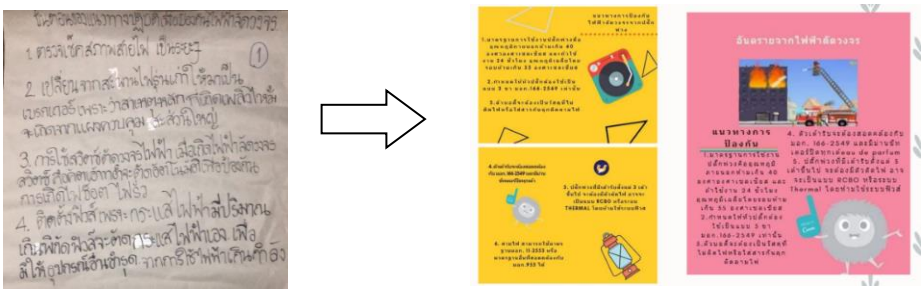

Figure 2 Students' developing ideas and revised prototype of guideline poster for short circuit prevention

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According to the figure 2, students drew up their ideas of solving problem to develop prototype regarding on the Hynes et al. (2011) engineering design process (EDP). They identified the problem about "how can we prevent short circuit?" They developed ideas for their data collection via searching information for several kinds of electrical circuit that could be possible getting the short circuits. These included circuits of multiple electrical appliances, circuits with using poor-standard electrical equipment, and so on. Students, then, applied knowledge to develop some ideas of guidelines for short circuit prevention methods. For examples; people should use standard power sockets and electrical devices, and they should not be plugged by too many electrical appliances. According to making decision stage, students selected a poster for short circuit protection concerning with various practical guidelines. In design and implementation, students shared their ideas of guidelines poster on social media.

Regarding on students' performance, the researchers interpreted that the guidelines could not fast facts and visualized ideas in order to suggest people to follow the guidelines. Therefore, it could not be concluded that the guideline poster for short circuit prevention could not well provide practical and reasonable views of awareness for people. Based on the above the description of students' performance, two examiners' evaluation on the O-LISA and P-LISA revealed that students could be interpreted for component of critical thinking and problem solving skills in good level (average score 72.69%), component of communication and collaboration skills in very good level (average score 82.02%), and component of creativity and innovative skills in poor level (average score 42.56%) as showed in the table 4. Based on these three components, the students' learning and innovation skills of the 21st century could be interpreted as fair level.

3.3 Student group of safety electric wire protection was evaluated as good level of competency on learning and innovation skills

Student group of safety electric wire was evaluated as good level of students' competency on learning and innovation skills of the 21st century. Students pointed out the key concepts for safety electrical wire by starting from identifying the problem through the questions: "what to do to keep the whole family safe from electrical leakage and short-circuits?" They summarized that the accidents may occur because the power wires were deteriorated, damaged, worn-out, leaked by animal bites. If there was a "leak" when we touched the wire, it was called "electrified." This would not cause a short circuit because we touched only one line of electric wires. Students clarified basic ideas of designing the safety electric wire that related to key concept of short circuits. They mentioned that the reason of short circuits was about the touching of two lines of electric wires. They then, designed something that protect two wires never touch each other. Based on this idea, they learn how to optimize their design and developed a prototype of safety electric wire protection as showed in the figure 3.

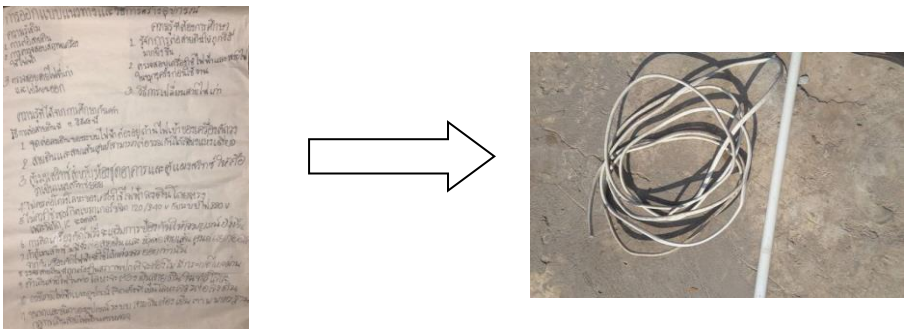

Figure 3 Students' developing ideas and revised prototype of safety electrical wire protection

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According to the figure 3, students drew up their ideas of solving problem to develop prototype regarding on the Hynes et al. (2011) engineering design process (EDP). They identified the problem about "how to make everyone in the family safe from electrical leakage and short-circuit?" They developed ideas for their data collection via searching information for several kinds of causes of short-circuit (e.g. overusing electric wires, dilapidated conditions of the wires). They were thinking about the methods of protecting the touching between two lines in the electrical wire. They listed some protection methods to recheck if conditions of the wire caused by animal bites or typical deterioration. In the making decision stage, they selected an approach to construct devices to protect the touching of two lines in the electrical wire. Their design and implementation was about method of putting the electrical wire into the PVC pipe.

Regarding on students' performance, the researchers interpreted that the safety electrical wire protection was developed based on preventing the wire away from animal biting that allowed the touching of two lines in wire. However, students should also take other factors for designing the preventing of touching of two lines. Based on the above the description of students' performance, two examiners' evaluation on the O-LISA and P-LISA revealed that students could be interpreted for component of critical thinking and problem solving skills in good level (average score 72.80%), component of communication and collaboration skills in very good level (average score 87.29%), and component of creativity and innovative skills in fair level (average score 60.80%) as showed in the table 4. Based on these three components, the students' learning and innovation skills of the 21st century could be interpreted as good level.

3.4 Student group of control breaker was evaluated as very good level of competency on learning and innovation skills

Student group of control breaker was evaluated as very good level of students' competency on learning and innovation skills of the 21st century. Students pointed out the key concepts for control breaker by starting from identifying the problem through the questions including what the causes of short circuits are, and what we should for protection of short circuits when the multiple power sockets are used at the same time. They discussed that short circuits were found because of excessive electric current generated over-heating and/or damaged power cords. Therefore, the group members designed an innovation to prevent short circuits by connecting the electric appliances with a breaker with an on-off switch. They indicated that breaker worked as well as general electrical switch; however, it could serve higher quality when it had circuit breaker, In addition, the on-off switch of the electrical circuit could be able to control and prevent overflow current in the circuit causing short-circuit. When it heated up in the electromagnetic fields, the circuit breaker would stop working by disconnecting the electricity. Based on this idea, they learn how to optimize their design and developed a prototype of control breaker as showed in the figure 4.

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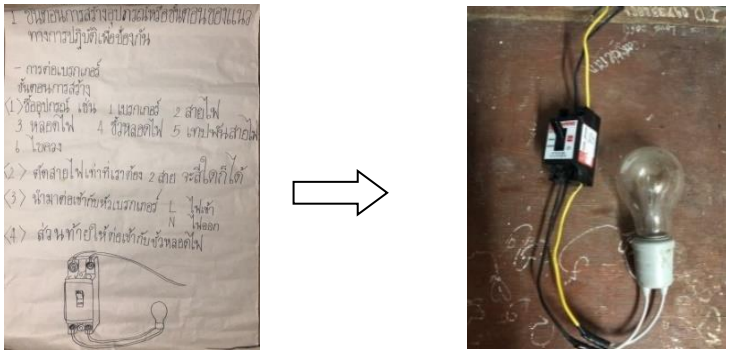

Figure 4: Students' developing ideas and revised prototype of control breaker

According to the figure 4, students drew up their ideas of solving problem to develop prototype regarding on the Hynes et al. (2011) engineering design process (EDP). They identified the problem about "plugging the multiple power sockets at the same time may cause electrical strapping problems" They developed ideas for their data collection when students summarized that the circuit breaker was one of the on-off switches like other general electrical outlets but had higher quality because of the circuit breaker could control and prevent overflown current in the circuit that caused short circuit. In the making decision stage, they selected the best possible solution of connecting the circuit breaker to control the electric current to prevent short circuit. Their design and implementation was about experiment of setting the circuit breaker to the household electrical appliances in order to control the overload use of electric devices. The overload use of electrical devices on some parts of circuits risks finding the short circuits around. In the testing stage, it was when students showed how the breaker automatically cut off the power, called breaker tip. Finally, evaluation was provided when students rechecked if "breaker works with various electrical devices in the household and can prevent the occurrence of short circuit."

Regarding on students' performance, the researchers interpreted that the control breaker was developed based on ideas of automatically opening circuits when there were over load of electrical devices in a circuit. It was vertical ideas to design the circuit breaker. Students could provide a prototype of circuit breaker regarding on their planning and theories. Based on the above the description of students' performance, two examiners' evaluation on the O-LISA and P-LISA revealed that students could be interpreted for component of critical thinking and problem solving skills in very good level (average score 85.15%), component of communication and collaboration skills in very good level (average score 84.65%), and component of creativity and innovative skills in fair level (average score 68.92%) as showed in the table 4. Based on these three components, the students' learning and innovation skills of the 21st century could be interpreted as very good level.

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3.5 Student group of circuit breaker was evaluated as very good level of competency on learning and innovation skills

Student group of circuit breaker was evaluated as very good level of students' competency on learning and innovation skills of the 21st century. Students pointed out the key concepts for circuit breaker by starting from identifying the problem through raising issues about many electrical devices and overloaded power use for a position. For example, students mentioned that there were too many electrical devices in a power socket. They clarified that too many devices electric use for single socket would affect to overheat and short circuit. The electric flow through it and generate overheat on a socket. The group members, therefore, invent a device to cut off electric flow when the electric current was overflown through the outlets. They mentioned that "to prevent short circuits, we could use the fuse connected to the electric circuit in the power sockets then turn on or off the switch". Their developing ideas and prototype could be viewed as the Figure 5.

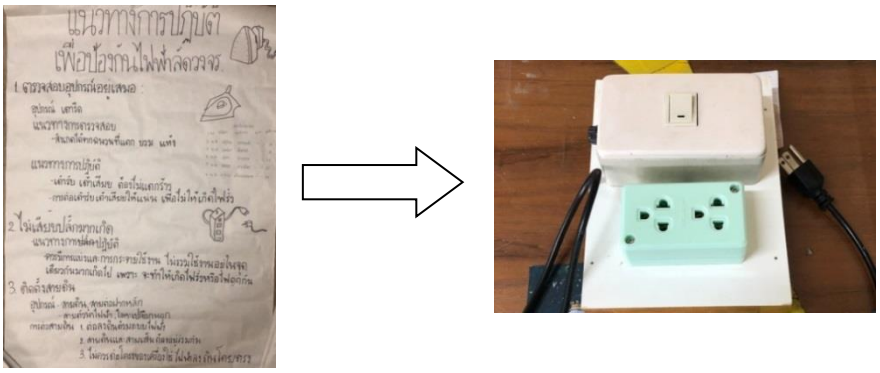

Figure 5 Students' developing ideas and revised prototype of circuit breaker

According to the figure 5, students drew up their ideas of solving problem to develop prototype regarding on the Hynes et al. (2011) engineering design process (EDP). They identified the problem about "plugging too many electric appliances in a power outlet causes a short circuit." They developed ideas for their data collection when students understood how electric strapping circuit caused overflown current before sparking and firing. They summarized that the prevention guidelines should provide a safety switch that cuts the power we overuse the current. In the making decision stage, they selected a method of constructing device for cutting electric circuit. Their design and implementation was about designing the power socket with a switch. In the testing stage, it was when students showed the techniques to cut the circuit when overload of power devices in the sockets. Finally, evaluation was when students reassess their prototype whether the fuse breakers could cut off when the current was overusing or overheating.

Regarding on students' performance, the researchers interpreted that the circuit breaker was developed based on ideas of how the prototype could be real world practical. Also, they could reassess whether the work piece could prevent the electrical short circuits.

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Based on the above the description of students' performance, two examiners' evaluation on the O-LISA and P-LISA revealed that students could be interpreted for component of critical thinking and problem solving skills in very good level (average score 89.17%), component of communication and collaboration skills in very good level (average score 88.61%), and component of creativity and innovative skills in good level (average score 73.01%) as showed in the table 4. Based on these three components, the students' learning and innovation skills of the 21st century could be interpreted as very good level.

3.6 Five group of students' learning and innovation skills for the 21st century in the STS Electric Unit

According to the assessment results of 5 groups from the O-LISA and P-LISA in section of 3.1 – 3.5, it could be mentioned that learning management based on STS approach of Yuenyong (2006) in the lesson of electricity and power enhanced students to develop prototypes of electric wire protection group, control breaker group, guideline poster for short circuit prevention group, safe electric wire group, and circuit breaker. It identified that learning activities significantly encouraged students to develop learning and innovation skills of the 21st century.

From Table 4 presenting different levels of quality of students' learning and innovation skills of the 21st century from the teacher's observation and of students' work evaluation, it is found that the group of control breaker and circuit breaker reflected a very good quality level because the problems were clearly identified with scientific knowledge and presentation of the work was clearly focused on testing the device until it can be concluded that the invented work piece could solve short-circuit problems. Likewise, students that showed the quality of learning and innovation skills at a good level were in the group of electric wire protection and guideline poster for short circuit protection. On the other hand, students were rated with a fair quality level of learning and innovation skills because although their work was rather clearly identified and related to scientific knowledge at the first stage, the task/prototype could not be completely usable in reality. The major reason was that students did not implement the stage of "testing" in order to conclude that the task/prototype could solve short-circuit problems in practice.

4. Conclusion and Discussion

From the findings, it can be concluded that in each stage of learning management based on Yuenyong (2006)'s STS approach consisting of 5 steps which are 1) problem identification, 2) potential solutions identification, 3) need for knowledge, 4) decision making process, and 5) socialization process. Each group of students develops learning and innovation skills of the 21st century. Students reflect behaviors and invention that demonstrate three major components of learning and innovation skills: 1) critical thinking and problem-solving skills with 4 indicators, 2) communication and collaboration skills with 3 indicators, and 3) creativity and innovation skills with 3 indicators at different quality levels.

In brief, the control breaker group and the electric breaker group preform with a very good quality level, followed by the safe electric wire group performing with a good quality level, the electric wire protection group. On the other hand, the guideline poster short circuit protection group could be performed with a fair level of quality.

However, all group reflected learning and innovation skills of the 21st century in a very good level because, in the 4th step (decision-making process), students presented and implemented solutions to the problems by identifying problems in step 1 with the

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engineering design process. Although the practices and presentations are different among groups, they solve problems with the engineering design process with the following steps. A) Problems or needs identification, B) Data collection, C) Making decision (Method selection), D) Design and implementation, E) Testing, and G) Evaluation.

Interestingly, the 6th step F) Revision which is used to test the practical prototypes whether it could prevent the occurrence of short circuits or not, is not significantly shown in all groups. Thus, most groups were assessed with a very good level of learning and innovation skills of the 21st century. For the group that was unable to test their work or unable to use the invented device in practice, so it could not be concluded that their prototypes could prevent the cause of the electric shock, was assessed with a fair level of learning and innovation skills.

In conclusion, the learning management based on Yuenyong (2006)'s STS approach should be conducted along with the engineering design process suggested by Hynes et al. (2011) to enhance students' learning and innovation skills of the 21st century. These innovative approaches provide opportunities for students to present their ideas, reflect their understanding of the relationship among major subjects (i.e. science, technology, mathematics, social studies) to solve current issues, and evaluate themselves to further develop their learning skills.

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