The design of STEM Education lessons on statistical mechanics for undergraduate students

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Abstract. Lessons combining of the integration of Science, Technology, Engineering and Mathematics or STEM Education were designed and used to enhance learning activities in a Statistical Mechanics classroom for undergraduate students at Ubon Ratchathani University, Thailand. Three STEM Education activities were introduced into the classroom including, solar drying project, magnetic induction, and heat radiation. The STEM Education activities will be described in details. The students were introduced to STEM Education and problem-based project learning. The students were trained to solve real problems by concentrating on engineering problems and then thoughtfully guided by instructor’s questions to apply all subject matter of Statistical Mechanics (Science) and techniques and student’s skills of Technology, Engineering and Mathematics. The students were able to gain and build up their own knowledge and skills necessary for 21st century. The students were impressed by the STEM Education activities. The students’ satisfactory toward the STEM Education activities was in the highest level.

1. Introduction
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 fueled when they find out enough to know that there are still questions to ask and things to investigate.
However, many teachers and professors in schools and universities have experienced with a large number of students in introductory classes. The courses are rich in content. Then, these courses often do not engage students in active, authentic scientific investigation, nor do they adequately concentrate on problem-solving process and inquiry skills required to further development. It has long been misunderstood that Physics has an image of being both difficult and boring [1, 2].

Decreasing motivation and competence in Science especially Physics studies among students at different levels has also been an issue broadly discussed by educators, researchers, and politicians. Some researchers found that one of the big problems was laboratory scarcity [3]. Our research shows we can use simple tools to do simple experiments and integrate subject matter in Physics and Mathematics so that the students may learn more contents [4]. We also show that these experiments may be used for the integration of science, technology, engineering, and mathematics (STEM) education. Then, instructors spend most of their time to lecture. As a result, these courses often do not engage students in active, authentic scientific investigation, nor do they adequately concentrate on problem-solving process and inquiry skills required to further development. Students may get concepts what they have learned, but they lack of skills necessary to survive in 21st century. Decreasing motivation and competence in academic proficiency and skills necessary to survive in 21st century among students at different levels especially college students are issues broadly discussed by educators, researchers, and politicians. The survival skills necessary to in 21st century include 6 areas: problem solving, creativity skills, self-help, rational thinking, technology literacy, and social skills.

Data analysis showed that the graduates of Ubon Ratchathani Rajabhat University (UBUR) and Ubon Ratchathani University (UBU) could not get jobs in their majors. The students could not link their knowledge they have learned to new knowledge what they are learning and could not build new knowledge based on background they have learned [5]. Therefore, in this work, we first intended to improve the teachers to develop teaching and coaching skills and then to improve teaching and learning methods by using the integration of science, technology, engineering, and mathematics (STEM) education into classrooms.

The purposes of this study were to develop learning management forms for developing STEM based instruction for higher education instructors on Statistical Mechanics for undergraduate students.

2. Theoretical Background

Faraday’s law states that [6] the induced electro motive force, emf ($\mathcal{E}$), in a circuit is proportional to the rate of change of magnetic flux, $\Phi_B$, through any surface bounded by that circuit. emf ($\mathcal{E}$) can be expressed in the following equation,

$$\mathcal{E} = -N \frac{d\Phi_B}{dt},$$

where $N$ is the number of turn of the coil. Faraday’s law experiment is set up as shown in Fig. 1.
Lenz’s law states that the induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop. Lenz’s law experiment can be done as follows:

**Figure 1.** The illustration diagram of Faraday’s law and an induced current.

(a) When a magnet is moved near a closed circuit, current flows in the circuit.

(b) When a current in an adjacent circuit changes, current flows (induced) in the circuit.

**Figure 2.** The illustration of Lenz’s law experiment. The current flowing in loop 1 induces the current in opposite direction [7].

Mutual induction can be explained as follows: Consider two coils as shown below, or inductors are close to each other, and a changing current in the first coil produces a magnetic flux in the second coil. However, the changing current in the first coil also induces a potential difference in
that coil, and thus the magnetic field from that coil also changes. This phenomenon is called self-induction. The resulting potential difference is termed the self-induced potential difference. Changing the current in the first coil also induces a potential difference in the second coil.

![Figure 3. Mutual inductance. A changing current in either coil induces an emf in the other coil.](image)

The magnetic property of materials can be studied by using metals with different magnetic susceptibility. The magnetic field, $B$, inside the material then depends on the external magnetic field, $B_0$, and the magnetization, $M$

$$B = B_0 + \mu_0 M$$

where $\mu_0$ is again the magnetic permeability of free space. Instead of including the external magnetic field, $B_0$, it is customary to use the magnetic field strength, $H$:

$$H = \frac{B_0}{\mu_0}$$

$$B = \mu_0(H + M)$$

Since the unit of magnetic field is $[B] = T$ and the unit of the magnetic permeability is $[\mu_0] = T m/A$, the units of magnetization and magnetic field strength are $[M] = [H] = A/m$. For most materials this relationship is linear: $M = \chi_m H$, where the proportionality constant $\chi_m$ is called the magnetic susceptibility of the material.

$$B = \mu_0(H + M) = \mu_0(H + \chi_m H) = \mu_0(1 + \chi_m)H = \mu_0 K_m H$$

where $K_m$ is relative magnetic permeability.

$$K_m = 1 + \chi_m$$
Table 1 Values of magnetic susceptibility for some common diamagnetic, paramagnetic, and ferromagnetic materials.

| materials                        | magnetic susceptibility ($\chi_m$) |
|----------------------------------|----------------------------------|
| paramagnetic                     |                                  |
| Aluminum                         | $2.3 \times 10^{-5}$             |
| Oxygen                           | $0.0002 \times 10^{-5}$          |
| diamagnetic                      |                                  |
| Copper                           | $0.98 \times 10^{-5}$            |
| Nitrogen                         | $-0.0005 \times 10^{-5}$         |
| ferromagnetic                    |                                  |
| Iron                             | $5,500$                          |
| Mu-metal (77%Ni-16%Fe-5%Cu-2%Cr) | $100,000$                        |

In Statistical Mechanics class, students have learned the probability of a dipole of magnetic materials pointing amarelle to an external magnetic field [8],

$$P(r) = \frac{e^{-\beta \epsilon_r}}{Z},$$

where $Z$ is a partition function. The average energy of magnetic energy is

$$\bar{E} = \sum r \epsilon_r \cdot P(r) = \sum r e^{-\beta \epsilon_r} = -\frac{\partial \ln Z}{\partial \beta},$$

$$\bar{E} = \frac{\mu H}{e \mu H/k_B T} \left( e^{\mu H/k_B T} - e^{-\mu H/k_B T} \right)$$

These equations will be applied to increase energy of a magnetic field.

3. Methods

Statistical Mechanics deals with microscopic points of view to describe macroscopic properties of matter. For example, magnetic field or potential energy of magnets (macrostate) depends on each tiny magnetic dipole (microsite). Most students do not realize until they experience real world problems or experiments. In our lesson design, we present the design of simple sets of apparatus for teaching on electromagnetic induction in an undergraduate level, science shows, and in-service teachers’ training courses. We show that useful experiments do not necessary to require expensive apparatus. The experiments include Faraday’s law, Lenz’s law, inductance, and magnetism of magnetic materials. We use inquiry method to challenge ability of new generation teachers and to use the integration of contents and pedagogical knowledge for teaching Physics. We will report the used of the experiment sets to demonstrate the concepts of the relationship between electricity and magnets through an inquiry method. This work can be used as a part of classroom innovation and the teaching-learning process reforms.

The engineering problems are as follows:
1. How can we induce magnetic field?
2. How can we increase the current?
3. How can we increase the magnetic field?
4. How can we observe the magnetic strength?
5. What materials should we use?
6. What temperature do we need?
These are STEM Education problems that students have to solve. The students were guided through the project. They have learned STEM skills as shown in table 2.

It is difficult to have magnetic flux in a coil changed by switching on and off manually. To do this, we apply an alternative current (AC) to the first coil and the change in magnetic flux in the first coil leads to generate an induced current in the other coil. To increase the magnetic flux in the coil, we use materials with high magnetic susceptibility. Students can perform an experiment by inserting metals such as aluminum, copper and iron as a core between two set of coils. The students can observe the effect of magnetic material cores by viewing the bright of the light bulb.

The student carried out the STEM project. The instructor provided materials, liquid nitrogen, light bulbs, copper wires, rings and others.

**Table 2** STEM Education that the students have learned from the STEM project

| STEM             | Contents and skills                                                                                      |
|------------------|--------------------------------------------------------------------------------------------------------|
| **Science (S)**  | Concepts of statistical Mechanics (Physics), partition function, average of energy, effect of temperature on average of energy (macrostate) |
| **Technology (T)** | Methods, techniques, materials                                                                         |
| **Engineering (E)** | Design, control, and process analysis, the use of engineering process                                     |
| **Mathematics (M)** | Calculation, approximation                                                                            |

4. **Results and Discussion**

The students worked in group coached by the instructor. They all found that best materials to generate strong magnetic field by induction was ferromagnetic materials such as iron and nickel because they have high value of magnetic susceptibility. It could serve as a core for magnetic induction. They can design experiments to prove the idea. They also learned how to increase magnetic field by lower temperature as they were guided as shown in Statistical Mechanics texts. The pictures below show the real work done by the students.

![Image of simple experiment for testing different magnetic materials core for mutual inductance](image)
The student used engineering process. The engineering process start with 1) identify the need or problem, 2) research the need or problem, 3) develop possible solutions, 4) select the best solution, 5) construct a prototype, 6) test and evaluate the solution(s), 7) communicate the solution(s), and 8) redesign to fit the need. They used engineering methods or process. For example, they used engineering processes in designing and planning to keep the lessons going. During teaching and coaching their students to learn so that their students could build new knowledge and skills, the lecturers found that they have learned new teaching methods and new experience. From the observation, the students appreciated the lessons. They enjoined working in group, presentation, and discussion. The students appreciated the lesson very much so that they have gone to teacher' trainer program at Faculty of Education, Khon Khean University after completing BS degree in Physics at UBU.

5. Introduction
We have developed STEM Education based instruction for undergraduate students at UBU which are located in Northwestern part of Thailand. The students were eager to acquire new method of teaching and learning, STEM Education for their classrooms. We have also applied new developed learning management lessons and plans on Statistical Mechanics to our classrooms. The students learned greatly and positively responded to the developed lessons. The students are able to solve real problems using STEM Education. The students’ necessary skills for 21\textsuperscript{th} century improved with significant satisfaction.
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