Mind map learning for advanced engineering study: case study in system dynamics

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Abstract. System Dynamics (SD) is one of the subjects that were use in learning Automatic Control Systems in dynamic and control field. Mathematical modelling and solving skills of students for engineering systems are expecting outcomes of the course which can be further used to efficiently study control systems and mechanical vibration; however, the fundamental of the SD includes strong backgrounds in Dynamics and Differential Equations, which are appropriate to the students in governmental universities that have strong skills in Mathematics and Scientics. For private universities, students are weak in the above subjects since they obtained high vocational certificate from Technical College or Polytechnic School, which emphasize the learning contents in practice. To enhance their learning for improving their backgrounds, this paper applies mind maps based problem based learning to relate the essential relations of mathematical and physical equations. With the advantages of mind maps, each student is assigned to design individual mind maps for self-leaning development after they attend the class and learn overall picture of each chapter from the class instructor. Four problems based mind maps learning are assigned to each student. Each assignment is evaluated via mid-term and final examinations, which are issued in terms of learning concepts and applications. In the method testing, thirty students are tested and evaluated via student learning backgrounds in the past. The result shows that well-design mind maps can improve learning performance based on outcome evaluation. Especially, mind maps can reduce time-consuming and reviewing for Mathematics and Physics in SD significantly.

1. Introduction

System Dynamics (SD) is one of the most significant fundamental subjects, which can be used to virtually model, applied engineering applications in the real world. To be more specific for significances in modern engineering areas, SD can be applied in a special modeling technology, especially, for reducing cost-prohibitive issue called “virtual sensor”. The concepts of this low-cost and effective sensor can be categorized in three criteria [1]: measurement characteristics-based criterion (transient-state and steady-state data-based approach); modeling method-based criterion (white-box, gray-box and black-box models) and application purposes-based criterion (replacement and observing) [2]. For first criterion, steady-state based approach is typically applied in quick modeled process from changed inputs or slowly changed inputs of a system, so it is suitable for intelligent diagnostic module called “automated fault detection and diagnosis (AFDD)”. Virtual sensor examples can be found in the recent literature such as virtual wall surface temperature [3] and refrigerant charge [4]. In contrast to steady-state method, the transient-state based approach using a
transient model to predict an immeasurable variable is typically appropriate for real-time feedback control or transient document used in FDD. With these behaviors, fast system responses such as chemical process control [5, 6] have applied transient virtual sensors to detect fast system changes due to existing faults and measure cost-effective values for a feedback control system.

In developed counties, beyond engineering program, several educational programs leverage this course in terms of educational programs [7-9] because this program can be used to initially test an innovative concept in terms of simulation-based modeling in any engineering areas before conducting a prototype [10]. However, since students have learned how to model any engineering system in terms of mathematical modeling, strong backgrounds in mathematics and physics are required for qualified students. For now, SD has been taught with lecture-based learning. The problems are: students in private schools lack of strong backgrounds in Applied Mathematics (e.g. Differential Equations) and Engineering Dynamics; as a result, these students cannot learn SD effectively and also cannot further applied SD in the continuous course – feedback control system for selecting optimal controllers to control the dynamic models.

To mainly enhance student learning with weak engineering and mathematical backgrounds, Woradechjumroen and Sinjindawong [10] applied project-based learning (PBL) as the idea of "learning by doing" [7]; each student group selected the project of a system modeling in the real world based on their backgrounds as the semester project. In addition, since PBL mainly relies on subjective rubrics based on instructor experiences for student satisfaction results in attending the course, outcome-based learning (OBE) method had been designed to evaluate how students can improve their performance compared with related student backgrounds before joining the class. Although the prior research can leverage some student performances, some students still cannot apply the accomplished project to similar applications because they cannot effectively link or create the relations between similar applications.

To reduce the aforementioned limitations, this paper proposes a mind map engineering learning for SD course. Firstly, student backgrounds are evaluated based on the designed course content relations. Then, the instructor will review and conclude the concept in terms of overview pictures. Then, the student learning is assigned via four projects for designing their mind maps for improving their studies. Mid-term and final exams are used to evaluate how students improve themselves efficiently.

2. Backgrounds and limitations

2.1 Course contents relation

In order to potentially evaluate the student study backgrounds, the course content relation relating to SD was designed as depicted in figure 1 [10]. In the figure, it illustrates the correlations of each related course in control engineering areas. As directly related course backgrounds to SD, the fundamental engineering background explains the phenomena engineering movement – Engineering Dynamics is significantly utilized to derive simplified mechanical systems in terms of rotational and transitional systems, whereas other systems are thermal, fluid and electrical system modeling do not associate with Engineering Dynamics. This is so challenging to develop potential mind map to link the three systems in one system for reducing required backgrounds in Heat Transfer, Fluid Mechanics and Electrical Engineering course, respectively.

In advanced engineering applications, especially relating to building energy systems, Building Control, Energy Modeling and Smart Building Solutions can be further assigned to interested students in building energy systems as cooperative educational students [11].

2.2 Student Backgrounds

According to designed course syllabus, the objectives of main map engineering method are that students who pass SD should be able to: 1) understand the phenomena of engineering systems; 2) know how to build mathematical modeling of an engineering system; 3) analyze system response via characteristics equation of the system modeling; and 4) understand similarity of thermal, fluid and electrical systems and the equivalence equation between mechanical and electrical systems. According to Table 1, it is evident that the class majority has weakness in mathematical solving problems. As a result, at least one mind map of each student were designed to improve and illustrate how to obtain the system response by using a mind map method.

| Related course backgrounds | Grade ≥ B | C ≤ Grade < B | D ≤ Grade < C | Do not enrol the course |
|---------------------------|-----------|----------------|---------------|------------------------|
| Engineering Dynamics      | 0         | 7              | 29            | 0                      |
| Calculus 3 or Differential Equation | 1         | 6              | 20            | 9                      |
| Calculus 2                | 12        | 12             | 11            | 1                      |
| Calculus 1                | 8         | 9              | 19            | 0                      |

3. Mind Maps Development Procedures

This section provides the general steps for constructing mind maps efficiently. At first, mind map theory and method are briefly explained to students with social science pattern. Then, the system overview of the course should be illustrated concisely composing of the general form of engineering system dynamics in terms of input, output and element. With the general form, system equivalence between mechanical engineering and electrical system is demonstrated via a mind map. Then, each
student will be evaluated by understanding the system similarities via transferring the designed mind map to associate with thermal, fluid and real world system. A further step, simplified mathematical solving procedures are designed to link the previous mind maps for obtaining system response. Then, the evaluation will be systematically conducted step by step to well notice student that performance improvement and any limitations of mind map utilization.

3.1. Basic mind map learning

Mind map was mainly designed to use the advantage of a right brain to memory any contents in system configuration instead of using only left brain which emphasize to use logics and theories [12]. As shown in figure 2, the related contents can be grouped together from the main concept or main feature in which action plan will link between the main system and each subsystem. With the good side, the instructor will teach students first and then will draw the conclusion in terms of mind map for each class. However, mind map has been intensively used in social science course rather than engineering courses due to the content complexity. Attending students are required to study basic general mind map concept for further applying in engineering education to improve their study performance.

![General mind map illustration](image)

**Figure 2.** General mind map illustration [12]

3.2. System Overview

In this step, the main system of SD includes: input, output and system element in terms of resistance (R), capacitance (C) and Inductance (L). The three elements are used to model mechanical and electrical systems. Also, force or current is a driving force condition or input for mechanical and electrical system, respectively. Meanwhile, velocity is equivalent to voltage as output of electrical system as demonstrated in figure 3. At this step, the instructor has to conclude all initial and fundamental concepts for the system modelling procedures.
3.3. System modelling equivalence

This section is to design mathematical models in terms of mind map 2, which this mind map is initially conducted with free body diagram with Newton’s law, and then is converted to electrical system without using Kirchhoff law, using system equivalence compensation (figure 4). With the system similarities, students who were poor in electrical system modelling can understand more processes. In addition, this method could be used for the learning exchange between mechanical and electrical engineering students.

Figure 3. System overview between input, output and element of mechanical and electrical system

Figure 4. Mathematical modelling mind map
3.4. Mathematical solving

After any students can well model the engineering applications in mechanical systems, the next step is to learn how to solve the system without strong mathematical backgrounds. In this class, trial solution in figure 5 is mapped in order to teach students how to solve transient response without using Laplace transform in case of 1 degree of freedom (DOF) or 2 DOF with constant input or step function excitation.

However, in case of 2-DOF with more complex inputs such as harmonic or periodic functions, trial solution technique is not suitable to solve non-homogenous equations. To tackle this issue, Laplace transform table with simple examples is used to build potential mind map for solving homogenous equations as shown in figure 6.

![Table Solution forms](image)

**Figure 5.** Mathematical solving mind map using trial solution
### Mathematical solving mind map using Laplace transform

#### Laplace Transform Pairs

| Laplace Domain | Time Domain |
|----------------|-------------|
| \( F(s) \)     | \( f(t) \)  |
| \( G(s) \)     | \( g(t) \)  |

1. \( F(s) + G(s) \) \( \Rightarrow \) \( f(t) + g(t) \)
2. \( F(a\cdot t) \) \( \Rightarrow \) \( f(\frac{t}{a}) \)
3. \( F(s)G(s) \) \( \Rightarrow \) \( \int_{0}^{t} f(t-r)g(r) \, dr \)
4. \( \frac{d}{dt}f(t) \) \( \Rightarrow \) \( sF(s) - \int_{0}^{t} f(\xi) \, d\xi \)
5. \( \frac{1}{s}f(t) \) \( \Rightarrow \) \( \int_{0}^{\infty} f(t) \, dt \)

Equation 1: \( s^2 \frac{d^2}{dt^2} f(t) + \frac{1}{2} \frac{d}{dt} f(t) = -\frac{1}{2} (f(t)) \)

Equation 2: \( s^2 \frac{d^2}{dt^2} g(t) + \frac{1}{2} \frac{d}{dt} g(t) = -\frac{1}{2} (g(t)) \)

\[ \text{Given:} \quad \text{Initial conditions:} \quad x(0) = 0, \quad \frac{dx}{dt}(0) = 0 \]

| \( L \) | \( T \) |
|--------|--------|
| \( R \) | \( \frac{1}{R} \) |

#### Figure 6. Mathematical solving mind map using Laplace transform

### 4. Student Performance Evaluation

#### 4.1. System relation

To test and evaluate trained students can understand and apply the mind map concept for other engineering areas beyond mechanical and electrical systems. One of the five reports called lab 4 is designed to evaluate these student outcomes as shown in figure 7.

In figure 7, the mind map example demonstrates the similarities between mechanical, electrical, fluid and thermal systems. Especially, the electrical system can be further used to model thermal network used for a thermal system, and can be used for flow diagram in a fluid system as well. After that, Laplace transform main map in figure 6 can be applied to accomplish transfer function and transient response based on inverse Laplace transforms.
4.2. *Extending mind map for more complex systems*

To test and evaluate how well trained students understand and can apply the mind map concept for other engineering areas beyond mechanical and electrical systems. One of the five reports called lab 4 is designed to evaluate these student outcomes as shown in figure 8.

![Diagram](image-url)

**Figure 7.** Multiple system mind map relation for final examination

**Figure 8.** System similarity for final examination
In the figure, the similarities of electrical, fluid and thermal systems are first to review in terms of generic components and elements for a system. After that, students should explain how complex systems in the right-side hand of figure 8 are related together by extending the left-side hand concept. This extension can tackle the original learning styles of the students who always remember problems and solutions without understanding of the physical meanings and concept. Eventually, the mathematical mind map will be also used to solve solutions of each complex problem.

4.3. Real Application Solving
To further test students’ performance for continuous courses and real world applications, one problem in a thermal system is designed by relating the mind map concept as depicted in figure 9 as lab 5. In this lab, the lecturer primary introduces a room thermal network with a heat pump application. All students are needed to apply their mind maps for constructing a room thermal equation with the heat pump. Then, Matlab Simulink is introduced by using the equations from aforementioned steps.

Due to using artificial outdoor air temperature in terms of a sine function, the add-in mathematical solver of Matlab is so convenient to obtain the continuous solutions rather using the original solutions from the mind map. With the revision of solving the equation, the problem is used to simulate how the heat pump performs in terms of under-sizing, proper-sizing and over-sizing. Runtime fraction (RTF) [13] is a simplified parameter for identifying the heat pump performance.

After learning the real world problem-based learning as the first mind map of lab 5, students are required to achieve the second activity for converting from the room heating system to a cooling system application. Similar to the heating solution, students must have an answer based on the simulation what the right-sizing cooling capacity of the room is.

![Figure 9. Real world application](image)

4.4. Post student performance based on mind map
Eventually, five reports are totally summed to 30 points from 100 points, whereas other 70 points are from mid-term exam both 15 points and final exam 50 points and attendance of 5 points. The study performance was based on mind map application is summarized as tabulated in table 2 by comparing with the student backgrounds in table 1. The interesting findings are: 1) 7 students obtaining higher than grade B who do not have strong backgrounds in Engineering Dynamics and Calculus 3 (only one
obtained B); 2) 9 students obtaining between C and B can improve themselves and studying the behaviors in terms of solution memorization since 6 students from the total remember the solutions when they attended Calculus 3 and the rest 3 students can leverage the study performance; and 3) the rest would obtained D+ and D because they are still concern the improved study method, and do not pay attention to apply mind maps for improving their study styles and performances.

### Table 2 student-learning results

| Student backgrounds                  | Grade ≥ B | C ≤ Grade < B | D ≤ Grade < C | Do not enrol the course |
|--------------------------------------|-----------|---------------|---------------|-------------------------|
| Engineering Dynamics                 |           |               |               |                         |
| Calculus 3 or Differential Equation  | 1         | 6             | 20            | D ≤ Grade < C           |
| SD student grade                     |           |               |               | D ≤ Grade < C and do not learn Calculus 3 |
| SD student grade                     | 7         | 9             | 11            | 9                       |

### 5. Conclusions

SD is a significant and fundamental engineering course to develop system modeling for testing engineering concept before producing a prototype. To study SD well, students are required to have strong backgrounds in Mathematics and Physics, which are not inherent behaviors of engineering students in private universities. To overcome these issues, the mind map application is proposed for SD course. The instructor briefly explains the main concept in each class by using mind maps. To evaluate how well students understand, they are required to accomplish 5 reports are designed for a new student study method in the course. The first two reports are designed for study familiarity of mind map application. Then, lab 3 and lab 4 are designed to extend the application for more complex systems. Finally, one of the real world applications is used as lab 5 to test how student can apply mind maps and improve their study behaviors and performances. We found that mind map engineering applications can reduce the complexity of mathematics and physics by mapping the similarity of each system and by using solving pattern of system similarity. Their study performances can be improved if users systematically design potential mind maps.

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