Teaching conceptual models in engineering research with mathematical model approaches

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Abstract. In the field of social science generally uses a conceptual model as an initial hypothesis of research. But in the field of technology and engineering, objects of study or research can be modeled in a more appropriate form. This research proposes the application of mathematical modeling approaches in the process of designing conceptual models. Using this approach it is hoped that researchers and students will understand more accurately the interrelationships between variables so that appropriate solutions can be proposed. The diagram that we recommend are influence diagram with the enhancement using stock and flow diagram, and causal loop diagram. The modelling process can be supported by System Dynamics Software.

1. Introduction.
Based on ABET, engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. " [1]. Engineering students must have the ability to apply mathematics and natural science to provide a solution to problems in society. The Accreditation Board for Engineering and Technology, the organization that accredits engineering programs in the United States, has shifted its focus to the documentation of student learning outcomes. [2]. Traditional engineering instruction is deductive, beginning with theories and progressing to the applications of those theories. Alternative teaching approaches are more inductive. Topics are introduced by presenting specific observations, case studies or problems [3] Some research has been done to explore the opportunity to use Student Centered Learning Approach, especially in engineering education [4] [5].

This ability can be done if the student has a proper understanding of the concept of how the behavior of the system he is studying. Especially if the system that he observes is a complex system. The more complex a study system is, then a solid conceptual understanding is needed so that the resulting solution is right and resolves the problem. Significant research shows that students often enter the classroom with tightly held misconceptions about the physical world that are not effectively addressed through traditional teaching. As a result, students are frequently able to solve problems that have been explicitly taught, but are unable to apply course concepts to solve real problems not seen in class. Failure to grasp prerequisite concepts also leaves students poorly prepared for more advanced study. [6]

The concept of a system and how the system works can be simplified in the form of the concept of cause and effect. The concept explains how one variable affects another variable. Conceptual models will explain how each entity affects the conditions of another entity. The wrong concept will produce the wrong solution. For engineers, the wrong concept will produce a design that cannot be implemented.
because it is contrary to the nature of the world. Or even if the design was able to be implemented, it will create unintended outcomes because the concept they use is not considering the true nature condition. So, the correct understanding of conceptual models is very important.

The universities in different countries follow their own curriculum development philosophies with the intention of producing "work-ready" engineers. ABET engineering technology criteria was introduced to rationalise the various curriculum development philosophies [7]. There is a lot of variant of engineering education and engineering profession. One kind of engineering education is Industrial engineering. This kind of engineering study about integrated systems. Integrated system is a system that contains man, machine, material, and method. Because of this variant component it will create complexity. Complexity is a combination of interdependency and variance [8]. When such a system is complex, understanding of the conceptual model of the system becomes increasingly necessary. In the current era, system complexity does not only occur on the object of industrial engineering. It also affects another kind of system that engineering tries to solve.

Universities need not only to address the students’ learning preferences but also equip them with the skills necessary to engage actively in the knowledge-building process [9]. Conceptual Modelling is an important part in knowledge building process. It can be treated as associative learning method. Associative learning is a broad category that includes much of our daily learning activities that involve the formation of associations among stimuli and/or responses [10]. However, in the research process conducted by students, there is not yet a standard diagram that can be used as a conceptual modeling standard. Through this paper, we try to examine what kind of diagram that can be used for Conceptual Modeling for Engineering projects and Engineering Research.

2. Method
The main method to solve this problem, as shown in Figure 1, is the comparison method. The paradigm used to select this model is to use the mathematical model approach. This was chosen because one of the criteria in the engineering field is to use the application of mathematics in designing things. Then a comparison is made between various methods, models, and diagrams that apply mathematical models. Another paradigm that is also used is system thinking. The concept of systems thinking is needed to solve complex types of engineering problems.

The first step is to analyze what models can be used. After that, an assessment is made between the models so that priority candidates are obtained. Of the several priority candidates, a more thorough comparison of strengths and weaknesses was carried out. From this comparison, the best models that can be used to design conceptual models are recommended.

![Figure 1. Research Method](image)

3. Result and Discussion
Here is several candidate of model [system thinker] [burgehugheswalsh]

1. 18 Words
2. Affinity Diagram
3. Conceptual Model
4. Context Diagram
5. Decision Matrix
6. Functional Failure Mode and Effects Analysis
7. Function Means Analysis
8. Functional Modelling
9. Graphical Analysis
10. Influence Diagram
11. Input-Output Diagram
12. Spray Diagram
13. Systems Map
14. Graphical Function Diagram
15. Structure-Behavior Diagram
16. Policy Structure Diagram
17. Tree Diagram
18. Behavior over time diagram
19. Causal Loop Diagram
20. System Archetypes
21. Matrix Diagram
22. Morphological Box
23. Multiple Cause Diagram
24. N2 Analysis
25. Quad of Aims
26. Rich Picture
27. Root Definition
28. Sequence Diagram
29. Computer Model
30. Management Flight Simulator
31. Learning Laboratory
32. Stock and Flow Diagram

From some of the alternative diagrams, several models or tools related to the needs of this study were chosen. One of the criteria which became the basis of the selection was that the model described the system concept. The model or tool must show the components or variables involved and display the links between the components and variables. The model also needs to be able to illustrate the relationship between variables in the form of mathematical models. Based on these criteria, the model chosen will be studied in more depth, as follows:
1. Influence Diagram
2. Stock and Flow Diagram
3. Causal Loop Diagram

![Figure 2. Example of causal loop diagram](image)

Of the three main candidates for the conceptual model, the strengths and weaknesses will be analyzed. The advantages and disadvantages of diagrams are based on selection criteria. Conceptual models have a function to guide researchers to be able to find the right solution based on the correct concept. Whereas this model could be a guide for students when they did their final research project.
The model chosen needs to be able to show if there is a wrong understanding of the system or if there is conceptual knowledge that still needs to be learned by students. Based on these needs, a number of assessment criteria have been prepared from these diagrams:

1. Include variable
2. Implementing Mathematical Formulation
3. Each arrow defines a cause-effect relationship between variables
4. The model can automatically give a hint when something wrong with the concept that is modelled

Based on these criteria, an evaluation of each diagram is carried out so that a deep understanding is obtained. The first criterion is the use of variables. The three diagrams illustrate the variables involved in the system. Why are these variable criteria so important. This is because the process of engineering research and engineering design has the objective to improve the performance of the system. Then the increase in performance can be measured by a variable. All three diagrams have variables that are attached to each icon. In causal loop diagrams, as shown in Figure 2, writing variables is simpler. Icons that contain variables are in the form of one type, which is a circle. Whereas in the influence diagram, as shown in Figure 3, each variable can be modeled into many kinds of icons. When it is a controllable variable, it will be modeled as a rectangle. Uncontrollable variable will be a cloud icon. Circle as in process variable. Oval as objective variable. In stock and flow diagrams, the icon used to image variables can be in the form of stock, flow, flow rate, and cloud. Influence diagrams are commonly used to design optimization models. While the stock and flow diagram is used to design the dynamics model system. Each model has a different purpose.

![Figure 3. Example of influence diagram](image)

The second criterion is the application of mathematical models. All of these diagrams implicitly display mathematical formulations in explaining the relationship between variables. Although for causal loop diagrams, mathematical models are not written in detail. This is different from stock and flow diagrams and influenza diagrams. For both models, each node or icon is required to have a clear interpretation of mathematical equations. In dynamic system simulation software, in the design of Stock and flow diagrams, the modeler must input the equation in each icon. If that isn't done, we can't run the model. There are several applications that apply causal loop diagrams. However, the software, is not required to input mathematical equations. There is no popular software that supports the drawing process of influence diagrams.

The third criterion used is whether each arrow in the model shows a causal relationship. This criterion is important in designing conceptual models. This is because, with a clear cause and effect relationship,
engineers can clearly do the engineering process needed. Engineers can choose to increase the value of a variable and then change the state of another variable. In the influence diagram, each arrow illustrates cause and effect in the formulation of mathematical models. Each arrow can have meaning: addition, subtraction, multiplication, or division. It clearly shows the role of mathematical formulation and also the role of causal relations. In a stock and flow diagram, as shown in Figure 4, each arrow has the same function as stated on the influence diagram. However, there are special arrows that function as flow, have a slightly different meaning than arrows in general. In causal loop diagrams, the causal relationship is clearly seen on the diagram without the need to explore the underlying mathematical model. The causal relationship is complemented by positive and negative signs that indicate the nature of increase or decrease. To illustrate a clear causal relationship, the Causal Loop diagram very clearly explains the relationship from the diagram view. However, the process of validating a causal relationship could be wrong. Influence diagrams and Stock and Flow Diagrams are not too expressive in describing cause and effect relationships. However, when viewed deeper, the causal relationship is described in more detail in the form of mathematical formulation.

This fourth criterion is the most important criterion in the learning process. A beginner who conducts research in the field of Engineering often does not understand the conceptual model of the system being studied. The system sometimes does not have a complete component, or there is a causal relationship that is not quite right. This will cause a wrong solution or wrong design. Therefore we need a model that automatically provides notifications and notifications when it turns out that the modeling process has been done wrong. This notification process can be carried out by a supervisor or senior lecturer who helps the design process. However, it will be more efficient if there is an automated system that is able to detect these errors so that errors can be anticipated early, saving human resources, and speeding up the design process.

![Figure 4. Example of stock and flow diagram](image)

The automation process can be supported by an application or software. The software needs to have a feature to provide information if there is an error in the design process. Of the three diagrams, diagrams that are assisted by a robust information system and are equipped with complete applications are stock and flow diagrams. This is because stock and flow diagrams can indeed function and be interpreted optimally in the context of dynamic system simulations. This is different from some other diagrams that are not intended to be operated in a simulation. This makes the stock and flow diagram has its own advantages. One of them for example using Vensim software, there are features that will provide information if it turns out there is an incorrect equation, or an incorrect unit. This is very helpful in the design process. Logical errors of conceptual model design will be seen if it turns out that the units of each equation and related variables are inconsistent and not verified. In addition, the equation that exists at each node will clarify the relationship between variables.

The software used for Stock and Flow diagrams can also be used for the other two diagrams. Especially for Influence diagrams. However, the software will be more difficult to apply to draw causal
loop diagrams. This is because there is no requirement to make a clear mathematical model in a Causal loop diagram. While the influence diagram is indeed required to make equations from each node and from each relationship between variables.

4. Discussion

So when compared between all the diagrams based on these criteria, Stock and Flow diagrams are the best. Influence diagrams can also meet these criteria by relying on the same software as stock and flow diagrams. Whereas Causal loop diagrams have not been able to meet these criteria.

Besides based on these four criteria, there are also other considerations in choosing conceptual model diagrams that can be used in carrying out the engineering research and engineering design process. Stock and flow diagrams do have a good level of detail. However, stock and flow diagrams have features that exceed the requirements. Stock and flow diagrams are able to model dynamic systems. Stock and flow diagrams do not only do modeling in one unit of time, but also do simulations for some time running continuously. In some engineering research and engineering design, this is needed. While the influence diagram has features that are not owned by the other two models, namely optimization. Influence diagrams have variables that can be treated as constraints. In some design processes it is also not necessary.

Based on comparisons that have been made to each model, based on each criterion, we propose to combine the features in the three diagrams proportionally. Users can use dynamic system simulation applications in drawing conceptual models. From the software the user can start creating simple conceptual models within the framework of influence diagrams. Influence diagrams as initial conceptual models that will be used in engineering research and engineering design. As a first step the user can choose not to use constraints. After describing several variables and their relationships, users can complete with mathematical equations so that the relationships between variables can be verified. Then the user can choose to apply the feedback loop as stated on the causal loop diagram. It is estimated that the application of stock and flow icons will not significantly affect the design of the conceptual model.

5. Conclusion

Model is a language used by humans to communicate. In the process of design and research in the field of engineering, the model is a means to communicate between research and design practitioners. Models also become a way to express the contents of the mind. So using the model can be known whether the thought is correct or wrong. There are several alternative models of system thinking that can be used. However, in the context of the process of designing conceptual models in the field of engineering research and engineering design that are increasingly complex in this era, we recommend utilizing the features that exist on influence diagrams, stock and flow diagrams, and causal loop diagrams. The main model recommended for use is influence diagrams, by allowing them to be equipped with features in causal loop diagrams and stock and flow diagrams.

Some further research can be done. One way is to do a new diagram that is indeed suitable to illustrate the conceptual model. Other research is designing special software that is intended for the design of conceptual models. This concept needs to be tested, so that the experimental process of using conceptual models in the teaching process can also be new research.

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