Reconstruction of collaborative problem solving based learning in thermodynamics with the aid of interactive simulation and derivative games

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Abstract. The reconstruction of thermodynamic learning aims to develop and innovate the student-centred learning. Another aim was to provide the students' 21st century skills such as problem-solving and reflective thinking skills through collaborative problem solving. Enhancement of students' ability to solve problems, effectively carried out in groups in which they are encouraged to exchange arguments, combine knowledge and skills in finding solutions. The reconstruction of thermodynamic learning was developed with the help of interactive simulations in abstract concepts, cycles and graph, and derivative games with the objective of assisting in the understanding of thermodynamic. Method used in this research was design and development research (DDR). There were two stages that had been done in this research: (1) the design and development model which was the design of CPS based thermodynamic learning model, and (2) the development of learning tools including: syllabus, semester learning plan, learning activity, and learning experience. The results showed that the difficulty in understanding abstract concepts could be overcome by the use of interactive simulations and derivative games. Therefore through the CPS model can be students are trained in cooperating, collaborating, arguing for solutions by utilizing technology and information to address world challenges in the 21st century.

1. Introduction
Thermodynamics is one of the topics in physics that gives description of macroscopic state, using mathematical and abstract concept, based on principles, and states processes and cycles. This must be made clear as it greatly affects students in understanding the concept of thermodynamics. Thermodynamic learning also explains many essential concepts but these concepts are not easily understood so that many students have misunderstood them in general \cite{1}. Another difficulty understands the concept of entropy, the Carnot cycle associated with entropy change \cite{2}. Apart from that, the greatest difficulty of learning thermodynamics is to find the relationship between one thermodynamic state variable and to solve the total differential equation that links the thermodynamic state \cite{3} and apply P-V diagrams for problem solving \cite{4}. Therefore, it is necessary to make some innovation in thermodynamic learning to overcome the problems faced by students in understanding the concept that is by using visualization for abstract concepts to understand the processes, simulation for...
understanding cycles and graphs, and derivative games for understanding mathematical concepts [5]. The simulation is focused on criticizing the abstract, complex concepts and phenomena in science education, thus helping students to learn easily and effectively [6].

Collaborative problem solving (CPS) is an important component of 21st century science career. This type of learning is promoted to solve problems in dynamic and interdisciplinary teams like scientists. Students discuss problems, explain and give opinions, debate, communicate and reflect knowledge collectively. At the same time, both educational researchers and practitioners note the dissonance between the demands of real-world scientific problem solving and current educational capacity to prepare an effective problem solver [7]. Problem solving as a specific form of collaboration has gained a great deal of interest for being a current educational initiative. [8] Collaborative learning encourages productive interaction and learning activities, such as asking, explaining, justifying opinions, articulations, arguments and elaborations. Through this process, learners verify and negotiate their individual views to achieve common understanding or group cognition [9]. The ability of students in solving problems is effectively demonstrated together or in groups to give each other arguments, combine knowledge and skills in finding solutions.

Based on the findings in the field in one of the private universities in physics education department in East Oku District of South Sumatera Indonesia, it was found that the thermodynamic learning applied by the lecturers was structured assignment, peer tutor, discussion, and lecture. In addition, based on the results of interviews to the students, they stated that the course was difficult to learn because there was an explanation of concepts with the mastery of mathematical physics, basic physics and many materials, which discuss abstract concepts. In addition, learning was more emphasized on the content. This highly affected the mastery of concepts and the ability of students in understanding the material, thus adversely affecting the learning outcomes. The concept, which is considered difficult by the students, is the concept of the Second Law of Thermodynamics and the understanding of mathematics on the concept of entropy. The supporting concepts in explaining law II and entropy are important to be explained clearly i.e. the basic concepts of energy and the first Law of thermodynamics.

To enhance problem-solving skills, reflective thinking and mastery of thermodynamic concepts it is necessary to reconstruct CPS-based thermodynamic learning on the concept of energy and the thermodynamic I law, thermodynamic II law and entropy. Through this learning, students can interact with groups to find solutions, exchange information and provide opinions with the help of interactive simulation and derivative games that are expected to assist students in understanding and mastering the concept of thermodynamics.

2. Method
The method used in this research is design and development research (DDR) [10]. This method has six stages: identification of problems, explaining objectives, design and development, testing, evaluation of test results, and communicating the results [11]. However, in this study we only came to the stage of problem identification, explaining the purpose, and design and development of the model. In figure 1, we can see the stages of research carried out.

![Figure 1. Stages of design and development of CPS-based thermodynamic courses.](image-url)

Stage 1: Problem Identification
- Analyze the syllabus of thermodynamics course. Field studies (lecturer performance in thermodynamics lectures, literature studies, instructional media used, student activity sheets used during the learning). Identify the difficulties of prospective teachers in understanding the concept of energy and the first Law of thermodynamics.

Stage 2: Explaining the Purpose
- After identifying the problem then the focus is on the purpose of developing program of thermodynamic lecture based on collaborative problem solving with interactive simulation and derivative games to improve problem solving ability and reflective thinking.

Stage 3: Designing and Developing
- Designing and developing lecture program according to needs analysis, which consists of designing course programs, making syllabus, semester learning plan, learning activities, teaching materials, student activity sheets, test instrument for problem solving ability and reflective thinking skills.
This research has reached the third stage, which is designing and developing the model at which we have developed the design of course programs, syllabus for the course, semester learning plan and activities undertaken in the learning of thermodynamics. The study was carried out in a physics education department in one of the teacher training and education schools in the south-Sumatra kabupaten OKU Timur Indonesia. The students as research subjects were even semester students enrolling thermodynamics course.

3. Result and discussion

3.1. CPS learning design

The reconstruction of thermodynamic learning is tailored to the current educational development for sharpening the thinking skills and is adapted to the challenges of the students in dealing with the 21st century through collaborative problem-solving learning. Thermodynamics with abstract, mathematical, process understanding, cycle and graphic characteristics can be explained in interactive simulation and derivative games. Figure 2 is a learning design that has been developed based on student activities in problem solving, the needs in understanding the concept of thermodynamics and the skills to be achieved.

![Figure 2. CPS Design of CPS-based thermodynamic learning.](image)

Based on figure 2 it can be seen that collaborative problem solving learning model consists of: 1) presentation of the problem and determining limitation of the problem through a learning video, exploration of thermodynamic concepts in the lesson i.e. the concept on energy, thermodynamic law I, thermodynamic law II, and entropy and its application. Each concept of the thermodynamics has abstract concept and needs understanding of its cycles, process, and graphs. The entropy concept is greatly emphasized on mastery of mathematics. Interactive simulations and derivative games are used in the explanation of thermodynamics aimed at improving the mastery of concepts so as to facilitate the search for solutions in problem solving. Student Activity Sheet is used as a learning medium that contains indicator of problem solving and reflective thinking or instruction to be done by the student. It is also equipped with the contents of the material and description of the context of the problems that will be solved by students collaboratively. The goal to be achieved in the learning of CPS-based thermodynamics is to improve the ability of prospective teachers’ problem solving and reflective thinking skills.
3.2. Interactive simulation in thermodynamic learning

Physics Teaching with Interactive Simulation has now shown great potential for improving learning and has been heavily incorporated into instructional activities to help educators achieve learning goals [12]. Simulations are suggested to create a new horizon for students in various learning that is learning a series of facts or theories about a particular subject [13]. In the learning of thermodynamics, for example, thermodynamic processes in heat engine is isothermal expansion process, adiabatic expansion, isothermal compression and adiabatic compression [14].

Figure 3. Explains the process of thermal machine.

Figure 3 explains the process of thermal machine. In the learning of thermodynamics, it is not enough just by looking at the picture. It is necessary to reconstruct this learning by a simulation by moving the piston to observe the process of heat change into work and the process of decreasing the temperature followed by the simulation of the concept curve in each process of thermodynamics. This is very helpful to educators in providing explanations to students about abstract concepts. In this interactive simulation, the same physical phenomenon can be represented in words, with equations, animations, graphs, and numeric tables or diagrams. Displaying animations from dynamic systems and connecting them to a diagram or coordinated diagram can help learners develop their skills in using different representations. The simulation program can help in some way as it visualizes the value of abstract properties during the thermodynamic process, enabling an experimental approach that complements theoretical derivation. The simulation program has a very positive effect on students who participate more actively in lectures, experimenting with systems and using the programs at home to learn. Therefore, students gain a better understanding of the thermodynamic process and obtain higher marks in the final exam [15].

3.3. Derivative games

The theoretical game of the epistemic framework was developed to describe the procedures used by students during solving physics problems [16]. They show that this framework is useful for investigating students’ understanding and use of mathematics in the context of physics. Partial derivative games are an epistemic game (exercise or simulation) used to solve thermodynamic problems in mathematical concepts. One of the thermodynamic challenges is that the relationships between numbers are not always easily seen and thus relate to partial derivatives. First, let’s play a functional analysis game [5]. This section describes three substitution epistemic games, Partial Derivatives, and Differentials. These experts play or propose solution when solving the concept of thermodynamic problems. Determine \( \frac{\partial U}{\partial p} \) gas van der Waals by using the equation \( P = \frac{nRT}{(V-nb)} - \frac{n^2a}{V^2} \). Epistemic form for this game and some key movements are summarized [5] in table 1.
Table 1. Summary of epistemic targets and key movements for each epistemic game.

| Games          | Key moves and hindrances                                                                 |
|----------------|------------------------------------------------------------------------------------------|
| Substitution   | \( U = U(p, S) \) Isolate one variable as a function of the desired variable; replacement for one expression to another |
| Partial Derivative | \( \left( \frac{dU}{dp} \right)_n = \left( \frac{\partial U}{\partial p} \right)_T \left( \frac{\partial U}{\partial T} \right)_p + \ldots \) Repeated use of partial derived derivative rules: a step must produce a good device |
| Differential   | \( dU = \left( \frac{\partial U}{\partial p} \right)_T dp + \left( \frac{\partial U}{\partial S} \right)_T dS \) Find the difference, linear algebra |

Partial derivative game is one of the epistemic games as a tool for performing cognitive task analysis. By using this epistemic game task, analysis can be performed on mathematical problems in thermodynamics [5]. So, partial derivatives games can be used as a tool in understanding the concept of mathematical thermodynamics.

4. Conclusion
The reconstruction of student-centered thermodynamic learning is supported by a collaborative problem-solving model in the mastery of the concept of thermodynamics has been successfully established. The difficulty in understanding abstract concepts is expected to be overcome by the use of interactive simulations and derivative games in the mastery of thermodynamic mathematics. Students are trained in cooperating, collaborating, arguing for solutions by utilizing technology and information to address world challenges in the 21st century.

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