# Authoring a Thermodynamics Cycle Tutor Using GIFT

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**Abstract.** The main idea of generalized intelligent tutoring system (ITS) development tools like Generalized Intelligent Framework for Tutoring (GIFT) is to provide authors with high-level standards and a readily reusable structure within different domains. Hence, adapting such a tool could be the best way to boost an underdeveloped tutor. In this paper we propose the design for a new GIFT-based tutor for undergraduate thermodynamics. An existing Thermodynamics Cycle Tutor has been designed that is meant to facilitate problem framing for undergraduate students. We describe the advantages of integrating this tutor with GIFT to add student models. Also an approach for evaluating the pedagogical performance of the GIFT-enhanced tutor is described.

**Keywords:** GIFT, intelligent tutoring system, thermodynamics cycle

## 1 Introduction

One of the most important challenges for engineering students is problem solving. Complex engineering problems typically contain multiple constraints, require multiple ideas, and may not have clear criteria for deciding the best solution. Beginning students struggle with engineering problem solving, and it has been observed that the initial stage (i.e., framing the problem) often causes the most difficulty. Students find it difficult to frame a complex problem, identify the core components, and brainstorm a possible solution path. These difficulties triggered the idea of building a tutor that can help undergraduate engineering students with their problem framing.

Thermodynamics cycles were our choices of topic to start with. In a National Science Foundation (NSF) funded project, a web-based software was developed to give students the ability to draw some initial sketches of the problem. Their drawing will be evaluated with regard to the expert model provided by the instructor and respectively they will be provided with different types and categories of feedback and instructions.

Regardless of how much effort is devoted to a project, there is always room for improvement. Key advantages of a generalized approach to ITS development (and GIFT in particular) are their standards and their high potential for reuse across educational and training domains. Other advantages that drive efficiency and affordability are GIFT's modular design and standard messaging; its largely domain-independent components; and its reuse of interfaces, methods, and tools for authoring, instruction, and analysis. Given these GIFT characteristics, there are many ways that the tutor could be enhanced being incorporating into GIFT. This will also provide us with an invaluable testbed to examine a GIFT-enhanced tutor with the existing one.

In the following sections, first a brief description of the tutor will be given and then an overview of the ways that the existing tutor can be enhanced by GIFT will be demonstrated. Finally a testing opportunity for the software will be described.

## 2 Current tutor

We would like to describe our current intelligent thermodynamics cycle tutor for engineering undergraduate courses. For the purpose of conceptualization and design, an ITS is often thought as consisting of several interdependent components: domain model, learner model, expert model, pedagogical module, interface and training media (Beck, Stern & Haugsjaa, 1996; Sottilare & Gilbert, 2011; Sottilare & Proctor, 2012).

### 2.1 Domain model

The domain is about thermodynamics cycle problems. The goal is to understand how changes in pressure, temperature, specific volume and entropy interact with some commonly-used components, such as pump, compressor, turbine, expansion value, evaporator, heat exchanger, liquid-gas separator and mixing chamber. Based on the physical and chemical properties, a rule is associated with each component. For example, when an object goes through a pump, the pressure will increase, while the temperature and specific volume will increase slightly. In the final version, the author will have the option to modify the rules (e.g. to assume constant specific volume, or to test a student with a component that doesn't make physical sense). The table below shows the rules associated with other components. The domain model contains these rules.

**Table 4.** Rules for several components

| Component | Pressure | Temperature | Specific Volume | Entropy |
|---|---|---|---|---|
| expansion valve | decease | decrease | Increase | Increase |
| evaporator | Same | same, increase | Increase | Increase |
| compressor | increase | Increase | decrease | same, increase |
| mixing chamber | same | between | between | between |
| condenser | same | decrease, same | decrease | decrease |
| Liquid -gas separator | same | same | between | between |

## 2.2 Interface

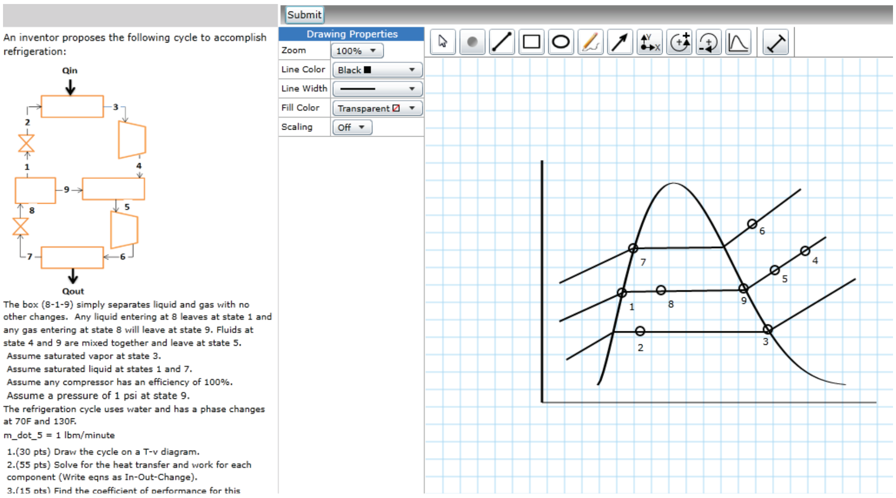


**Fig. 5.** A screenshot of Thermodynamics Cycle Tutor. The student reads the problem at left and solves it by constructing a vapor dome diagram at right.

Thermodynamics Cycle Tutor has been developed as part of a problem framing research project funded by the National Science Foundation. The tutor basically contains two parts. On the left side, it contains system/component diagram, problem description and questions. The right side uses a web-based drawing interface, XDraw, developed internally by author Jackman using the Microsoft Silverlight framework. XDraw supports basic drawing objects such as vapor dome, point, line, rectangle and vector as well as freehand drawing. It also provides facilities to allow students to label the states and insert text on the drawing. A backend database saves students' diagrams. XDraw communicates with tutor server via a TCP socket. Several message types are defined in order to differentiate what information would be checked and the next action should be taken.

When it starts, the left side shows the system diagram and problem description. Students can start problem framing by drawing a vapor dome (T-V diagram in this case) and use lines and points to represent pressure curve and state, respectively, and apply labels according to the system diagram. After clicking submit button, the diagram is sent to the tutor server, which checks a specific part based on the query message. The tutor then sends back the evaluation result and instruction for the next action as a returned message. Students may be directed to another interface based on their performance in the current stage. We will talk about the detailed sequences in the expert model.

### 2.3 Expert model

The expert model sets standards and compares learner actions to determine the progress. In the thermodynamics cycle domain, the expert model contains the following:

1. Check vapor dome present.
2. Check number of pressures.
3. Check number of states.
4. Check Pressure and Temperature relations in each of the components.

After the student submits the drawing, the tutor will check if the drawing contains the vapor dome. If so, it will continue to the next check: number of pressures. If it is wrong, the students will be asked questions like, “How many pressures are there in the system?” showing on the left panel. If the student’s answer is wrong, the tutor will go through all the components, and ask the pressure change within each of them. Some tutorial videos and illustrations will be provided to help them better understand the concept.

The content on the left panel will be changed based on the student’s activity in a particular problem. For example, in the drawing, the student draws state 4 to the right of state 3. A compressor pushes the gas molecules closer together, so specific volume should decrease. The left panel will show a compressor’s diagram, along with some questions, such as “How does the specific volume change in a compressor?” It contains several choices that students can select. If the student chooses the correct answer, it will ask the student to correct it in the diagram. If the student gets the wrong answer, it will direct the student to some tutorial video files and ask again.

### 2.4 Training media

In order to help students correct their misconceptions, the tutor provides some video files that include class lectures and illustration videos at a certain stage of the activity. The video files will be loaded automatically to ask students to watch when their answer is wrong. Generally speaking, the training media is domain-dependent and requires the instructor to prepare and pre-define what stage it should appear.

### 2.5 Learner model

Currently there is no learner model in our Thermodynamics Cycle Tutor. We think it is a good idea to monitor and keep track of students' current progress, save students' previous performances, and perform surveys. An example could be when student starts a new problem, the tutor should be able to select an appropriate problem from the learner model and predict how successful the student will be based on his/her historical data. Also, in the survey part, the tutor could receive feedback on the learner's background knowledge and quality of the pedagogical process. We believe GIFT could allow us to build a learner model easily, and we would like to explore how it may benefit our tutor.

### 2.6 Pedagogy

As a pedagogical learning tool, the tutor also needs to set up learning goals and pace for the students, so the student can learn each component's P, T, and V behavior one at a time (starting with the easiest one, and increasing difficulty as easier ones are mastered). The ideal tutor would be able to connect with other thermodynamic understanding, using ideas such as rate of heat transfer and rate of work (power) to connect with P, T and V relationships. For students with different performance levels, the problem difficulty should vary. The tutor's feedback has to inspire their thinking, not give them answers directly. The pedagogy module requires much flexibility and should vary based on different problem sets and instructor-student needs.

## 3 GIFT-enhanced tutor

The existing tutor is expected to demonstrate an acceptable functionality; however, there are limitations in its domain independence and reusability, and it also lacks some desirable features such as a learner model. Mitigating these limitations will require a considerable amount of time and programming effort. GIFT offers many features that can attenuate the level of programming skill and time required. Also, providing standards and well-defined domain independent structures facilitates the tool enhancement. The main benefits of GIFT for our tutor are explained below.

### 3.1 Learner model

A highly desired feature for intelligent tutors is to provide learners with personalized education (Woolf, 2010). In other words, if we could know the exact skills that learners do and do not have, then we could provide them with the exact resources they need. Learner model is a module that has been developed for this reason. Learner model keeps record of many aspects of the learner, such as the learner's progress toward objectives, actions taken in the interface and historical data (e.g., previous performance) (Sottilare, 2012). There is also a need to define some skill levels with respect to the learner's patterns. Having this valuable information about the learner and their skill, the tutor will be able to provide him or her with specific problems, feedback, instructional content, etc.

In our current tutor there are many data streams that are monitored (e.g., the mistakes or feedback types, instructional content provided, etc.). Also, by handing out surveys, some information about knowledge background is available. The problem is they are stored in separate databases and it is hard to put them together. Putting these data together can help us build the student model. GIFT provides the ability to store this data in a well-structured way, as it has the option for sensor data storing. In addition, we can benefit the GIFT survey authoring tool, to conduct our surveys in the same program and store them easily in the proper place. In this way, by defining the skill levels we will be able to build our learner models based on the data we have collected from them.

Another important feature is data reporting. Having collected a considerable amount of data on the learner, an easy-to-access way to extract knowledge out of it is necessary. The GIFT event report tool provides a proper interface to easily let users (instructors) access the data they desire.

For any further research, we might want to use different types of sensors to evaluate a learner's cognitive load or status or stress. GIFT provides the ability to readily acquire that data as well.

### 3.2 Multiple scenarios

Once skill levels have been assigned to learners, appropriate content must be provided based on those skills. To handle various types of problems and instructional material (i.e., Domain Knowledge Files), a precise structure is needed to store them. For this, GIFT Domain Authoring Tool (DAT) will be used. Since this tool can be used without having to launch the entire GIFT architecture, it enables us to benefit from it earlier in the development process.

In addition, different instructors have different pedagogical strategies and instructional content. Thus, they may want students to go through a different scenario or visit different content. Two of our co-authors, for example, have different pedagogical preferences for teaching the thermodynamic cycle. Based on their preferences, GIFT could enable us to create multiple scenarios appropriately. Without having a perfect match between the knowledge database and the tutor, accommodating multiple approaches would not be possible. However, GIFT has already provided the structured database, so making the linkage between the tutor and GIFT DAT will be helpful.

### 3.3 Expansion to other domains

The domain-independent structure of GIFT will enable us to simply customize our tool for different fields. Currently, statics problems, e.g., free body diagrams, can also be tutored via our tool, but using the Domain Authoring Tool that will facilitate the deployment of instructional material. The entire process of student model and learner-specific instructions could be implemented with this approach as well.

## 4 Proposed evaluation experiment

In the Fall 2013 semester, a thermodynamics class will be offered for undergraduate mechanical engineering students in Iowa State University. Early in the semester they will be divided into three groups. One group will work with the GIFT-enhanced tutor, another group with the existing tutor (without student model), and the last group will just join the class and have no tutor. Keeping records of the three groups' performances during the semester with periodic quizzes, as well as gathering data on their skills and solution time, will provide us with a valuable data to evaluate the performance of an intelligent tutor with the student model (GIFT-enhanced). It will also help us examine the effectiveness of the existing tutor.

## 5 Conclusion

After analyzing the features of our existing tutor and GIFT, they seem to complement each other perfectly and provide a comprehensive ITS. Using GIFT's standards for structuring the tutor, as well as data and file storing, will attenuate the requisite programming skill and effort to accomplish the same objectives. Also, its high domain-independence will create opportunities to expand the tutor to different learning domains. The GIFT-enhanced tutor will be compared with the existing tutor and with traditional class training during the 2013 Fall semester. The results could provide a documented comparison between two different methods of ITS development.

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## Authors

***Mostafa Amin-Naseri:*** is a Master of Science student in Industrial and Manufacturing Systems Engineering in Iowa State University. His BS was in industrial engineering with a major in systems engineering. Having had an experience in tutoring high school and undergraduate students he got familiar with common mistakes and issues that students usually face when solving problems and also the necessity for personalized instructional material. This background led him to start working on Intelligent Tutoring Systems (ITS). He is currently working with a team on an ITS that helps undergraduate engineering students with problem framing in Statics and Thermodynamics. Applying statistical analysis and data mining techniques to learners' historical data in order to come up with learner models, evaluate skill levels and to offer customized instructional material and feedback, is one of his fields of interest. Finally, with a systems engineering background, he is also interested in analyzing and simulating the learning process using System Dynamics models.

***Enruo Guo:*** a Ph.D. student in Computer Science co-majoring in Human Computer Interaction in Iowa State University. She got her Master's degree in Computer Science from Iowa State in 2012. She also had a background in pedagogy and psychology in her undergraduate study in Beijing Normal University, which is best-known for training school teachers in China. Her philosophy is to use computers to simplify human's learning process and make everything as simple as possible. She has broad interests in intelligent tutoring system, artificial intelligence, computer vision and virtual reality. She has strong enthusiasm in developing real-world applications to assist undergraduate teaching and administration. She develops Thermodynamics Cycle Tutor and now is working on Free-Body Diagram Tutor for engineering undergraduates. Furthermore, in order to reduce the workload of human inspector of Department of Chemistry, she develops Intelligent Safety Goggle Detector which can automatically detect if a lab user wears safety goggle at the entrance of the lab.

***Stephen Gilbert, Ph.D.***, is the associate director of the virtual reality applications center (VRAC) and human computer interaction (HCI) graduate program at Iowa State University. He is also assistant professor of industrial and manufacturing systems engineering in the human factors division. His research focuses on intelligent tutoring systems. While he has built tutors for engineering education and more traditional classroom environments, his particular interest is their use in whole-body real-world tasks such as training for soldiers and first responders or for machine maintenance. He has supported research integrating four virtual and three live environments in a simultaneous capability demonstration for the Air Force Office of Scientific Research. He is currently leading an effort to develop a next-generation mixed-reality virtual and constructive training environment for the U.S. Army. This environment will allow 20-minute reconfiguration of walls, building textures, and displays in a fully tracked environment to produce radically different scenarios for warfighter training. Dr. Gilbert has over 15 years experience working with emerging technologies for training and education

***Dr. John Jackman***: an Associate Professor, Industrial and Manufacturing Systems Engineering at Iowa State University, conducts research in manufacturing and engineering education. In manufacturing, he is currently working on wind turbine blade inspection techniques that characterize the variability in blade geometry and detect surface flaws. Dr. Jackman has extensive experience in computer simulation, web-based immersive learning environments, and data acquisition and control. His work in engineering problem solving has appeared in the Journal of Engineering Education and the International Journal of Engineering Education. He is currently investigating how to improve students' problem framing skills using formative assessment.

***Dr.Mathew Hagge:*** has built a teaching style for thermodynamics that simplifies the course into a small set of ideas and skills, and asks students to develop and apply these same ideas to novel situations. The same set of ideas and skills are used for every problem. No equation sheets or similar problems are used. Memorization is not needed, and will actually decrease student performance. Students are asked to make as many decisions as possible, subject to their level of understanding. As student knowledge and expertise increases, so does the problem complexity. Less than a dozen problems will be needed, but each new problem will push the student’s understanding. By the end of the course, successful students have the skills to solve any problem in a traditional textbook, and to correctly solve problems much more complex than a traditional textbook. When students need help, Dr. Hagge has developed a set of questions that can identify the specific misunderstanding, and then provide an activity or discussion that will eliminate the misunderstanding.
Dr Hagge’s teaching method is ideally suited for implementation with a tutor that focuses on student understanding. The tutor can measure specific skills/understanding and provide feedback unique to that student.

***Dr Gloria Starns***: received her Ph.D. in Mechanical Engineering from Iowa State University in 1996 and began instructing engineering students as a graduate student at Iowa State in 1990. Dr. Starns’ interest in working with a personal tutoring system is related to her past work with concept based learning, as well as understanding the role that use of active and constructive learning has in enabling students to retain and use acquired knowledge; her role in this project has been to provide the research team problems of varying complexity for purposes of collecting data from the tutor as it continues to evolve.

***Dr.LeAnn Faidley:*** is an Assistant Professor of Engineering Science at Wartburg College in Waverly, IA. She has a BS in Engineering Science and Physics from Iowa State University, an MS in Engineering Mechanics, and a MS and PhD in Mechanical Engineering from The Ohio State University. At Wartburg, Dr. Faidley teaches the freshman labs, the Engineering Mechanics sequence, the Design sequence, and Engineering Materials. She is interested in improving student engagement with engineering subjects through active learning, relevant projects, and interactive online tools.