Physical Climatology: 2- Layers

Date:

12/13/2019

Final Project：

Personalized Online Learning, Fall 2019

Vincent Aleven, Instructor

Jonathan Sewall, Co-Instructor

Team:

Hsing Liu, Tech

Jialu Li, Design

Table of Contents

Project Brief

Background

Global warming and climate change are in the center of the debate nowadays. Claims are polarized that some states global warming is a natural process, while the opponents claim that actions must be taken before it is too late. People tend to perceive climate change as very complicated and difficult to understand. But in fact, the basic mechanism of heat balance is not so out of reach.

One way to understand the greenhouse effect is by considering a simplified multilayer atmosphere model, where the atmosphere is presented as multiple fixed layers of perfect black bodies, but the energy from a star completely passes through them. This corresponds to the behavior of carbon dioxide and other greenhouse gases in the atmosphere, just that the real world is a lot more complicated. However, such as model is enough to give us some intuition of the greenhouse effect.

The purpose of this team project is to make a CTAT tutor for Professor Vaishnav's students in the graduate level Climate Change Science and Adaptation class. In this tutor, learners will do hands-on calculations for Earth's equilibrium temperature, in the case when there is no atmosphere, 1 layer, and 2 layers of the atmosphere. The steps of the tutor might correspond to calculating the solar power output, energy flow in and out the planet system, and the equilibrium temperature. The calculations are intended to reinforce their higher-level understanding of the effect of CO2 on the climate. Therefore, we may also try to incorporate some interpretation and self-explanation tasks. Since there is another group working on the same topic, we plan to further discuss how to split the tasks between the two groups.

Objective

By building this tutor, we hope to help the students understand the n-layer radiative transfer model that gives them an intuition of why the temperature is rising. By going through the tutor, the students should understand how energy balance between the planet surface and layers of atmosphere. The student may also come away with a better understanding of the basic mechanism underlying man-made climate change. Professor Vaishnav mentioned that he would like the students to be able to explain the greenhouse effect, but students often don't gain a good understanding through lectures alone. We hope our tutor will provide helpful pre-test practice to bridge that gap.

Scope

Domain: Physical climatology

Grade Level: Graduate level

Subject: Climate Change Science and Solutions

Professor: Parth Vaishnav

The combined scope of our two teams is to guide students to practice balancing energy from a planet with zero layer atmosphere to one with 2-layers, and then reflect on how additional layers of atmosphere may affect a planet's surface temperature. We then split the scope into 4 portions: fundamental knowledge of the variables, energy balance for a planet with zero layer atmosphere, energy balance for a planet with 1 layer of atmosphere, and the energy balance of multiple layers of atmosphere. Our team took on the multiple layers of atmosphere portion.

Research

Our two teams interviewed professor Vaishnav and reviewed his provided slides and recommended textbooks. We then set up a scope and a set of knowledge components. In our research, we hoped to uncover the exact learning outcomes expected by the professor, how much prior knowledge students have, and the knowledge components required for the students to achieve the learning outcomes.

Research planning

Type	Methods
Primary research	Interview, CTA, Self-test
Secondary research	Slides, Textbooks

Initial Findings

- Students have an undergraduate level of prior knowledge in physics
  - Students may know energy balance.
  - No need for in-depth instruction. Only use scaffolding on the difficult knowledge components
  - Use the tutor to correct the student's misconceptions
    - Write buggy rules for common misconceptions
    - Provide a further explanation in the buggy messages
- The instructor requires students to understand and be able to explain the greenhouse effect. The tutor may:
  - Short answer questions
  - Ask students to explain the formulas
  - Demonstrate how formula derives
  - No need to test the students' equation solving skills
    - No need to address equation solving skills
    - The tutor does the calculation for students

Testing

The two teams conducted Cognitive Task Analysis (CTA) to further verify and refine our scope and KCs.

CTA

We conducted think-aloud CTA to further verify our set KCs. To have a better understanding of the task we conducted CTA think-aloud with 3 students who have seen demonstrations solving similar tasks and the professor.

Task Design

The subjects are asked to think-aloud when solving the following question:

Assume a 2-layer atmosphere model, where the atmosphere is transparent to solar radiation and opaque to terrestrial radiation. Given solar constant S, albedo α, surface temperature T_s, the temperature of first & second atmosphere layers T_1 and T_2.

1. Draw a diagram of the model and label the heat transfers at equilibrium.
2. Calculate T_s.

Equations that students might use: Blackbody emission is σT^4. The amount of solar energy absorbed is $\frac{S(1-\alpha)}{4}$.

CTA Design

First, we asked the subject expert, Professor Vaishnav, to solve the problem. Then two members, Lilian and Jialu, assumed the role of novice students and did a think-aloud. Finally, we asked an actual student in the class to do a think-aloud. Although Lilian and Jialu are not actual students in the class, they are similar to the target novice learners who are graduate students at CMU, recently learned these materials, but still have misconceptions.

For each session, a step-wise analysis and raw transcript (using YouTube automatic transcription) are included in the appendix.

Subject Profile

Subject	About	Method
Student 1	Have prior knowledge to the knowledge from observing experts demonstrating solving similar problems multiple times.	Think-aloud
Student 2	Have prior knowledge to the knowledge from observing experts demonstrating solving similar problems multiple times.	Think-aloud
Student 3	Students of the Climate Change Science and Adaptation class learned the multi-layer heat transfer from a video lecture presented in class.	Think-aloud
Expert 1	Expert	Think-aloud

Findings and Insights

Strategies and Errors

The strategy used by every participant is similar. Write out how much energy goes in and out of each layer using unknown temperature variables, write equations that balance energy in and out in each control volume (but with possibly different choices of control volumes), and solve the system of equations (errors are highlighted and circled in yellow in the appendix_transcript). However, there are possible errors in each of those steps. One might mistake temperature for energy, not account for the correct energy in/out of a control volume, or have difficulty solving the equations. From the CTAs we hypothesize that people have seen, and may have some understanding of each of the key concepts, but not necessarily understanding them well enough. For example, please see the “Insights” column in the analysis section of the appendix.

Our tutor will guide the students to identify the amount of energy in and out of a control volume by asking them to input the energy into and out of the control volume, write an equation of energy balance, and then allow them to proceed to another control volume.

Revised Knowledge Components

#	KC		Note
1	The student is able to infer a simplified world phenomenon from comparing the surface temperature on a planet with no atmosphere to 1-layer of atmosphere to 2-layers of the atmosphere.		
	1.1	Given solar constant S, albedo, surface temperature Ts, the temperature of first & second-atmosphere layers T1 and T2. The student is able to come up with a representation of Ts. With provided Blackbody emission and solar energy absorbed functions	
2	Identify all the energy transfer.		
	2.1	Account for all the energy arrows.	Difficult
	2.2	Meaning of the variables.	
3	Energy Balance		
	3.1	Students are able to identify a control volume.	Difficult
	3.2	The energy in = Energy out, the student is able to account for all the energy in and out	Difficult

Production Rules

- If an object has temperature T, then (under simplified assumptions) it radiates σT^4 energy per unit area out of its surface

- Given a layer of atmosphere (that radiates σT^4 energy per unit area out of its surface), it radiates that same amount out of its top and bottom surface
- If energy from the sun is $S(1-\alpha)/4$, then that energy transparently passes through all the atmospheric layers and is absorbed by the surface (this is an assumption of the model)
- If some radiation energy from the planet surface or atmosphere hits the planet surface or an atmosphere, then that energy is totally absorbed (again an assumption of the model)
- Given a control volume in an equilibrium state with energy coming in and going out, the total of what goes in equals the total of what goes out
- Given a system of equations, solve for the target variable

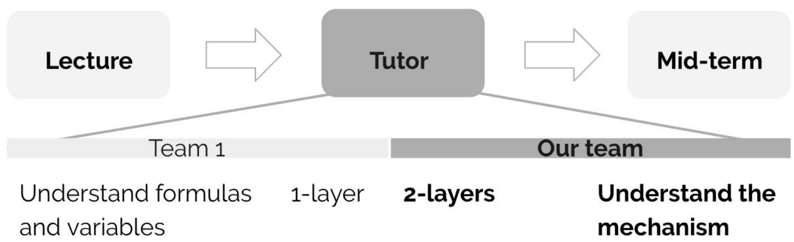
Solution

Updated Scope

As an update to our previously set scope the students are only expected to understand the basic mechanism underlying the greenhouse effect under a simplified model. Students don't need to memorize the formula, and doing the calculations is not so important.

Since we have found that students struggled with many details of how the model works, we decided to limit our scope to a 2-layer model, instead of extending to the more complex n-layer model. Also, instead of asking students to think about what one might infer about the real-world greenhouse effect, we would only ask students to infer what happens when additional layers of atmospheres are added under the simplified model.

The other group would create tutors targeted at basic building blocks of the model and up to 1 layer of atmosphere, so our tutor is a logical continuation of their tutors. Students who have completed the other group's tutors should have the prerequisite knowledge to try solving the more complicated 2-layer model, and make an inference based on all the previous results.

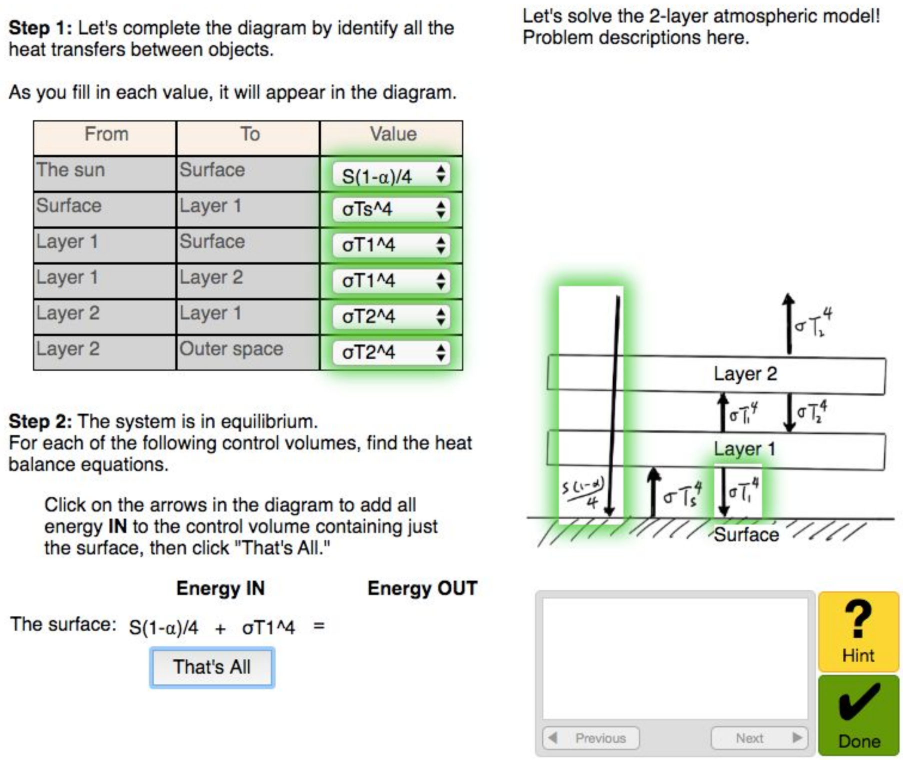


Ideate

Prototype

Example Tracing Tutor

(https://www.youtube.com/watch?v=TYsoG6ckQ_M&feature=youtu.be)



Feedback

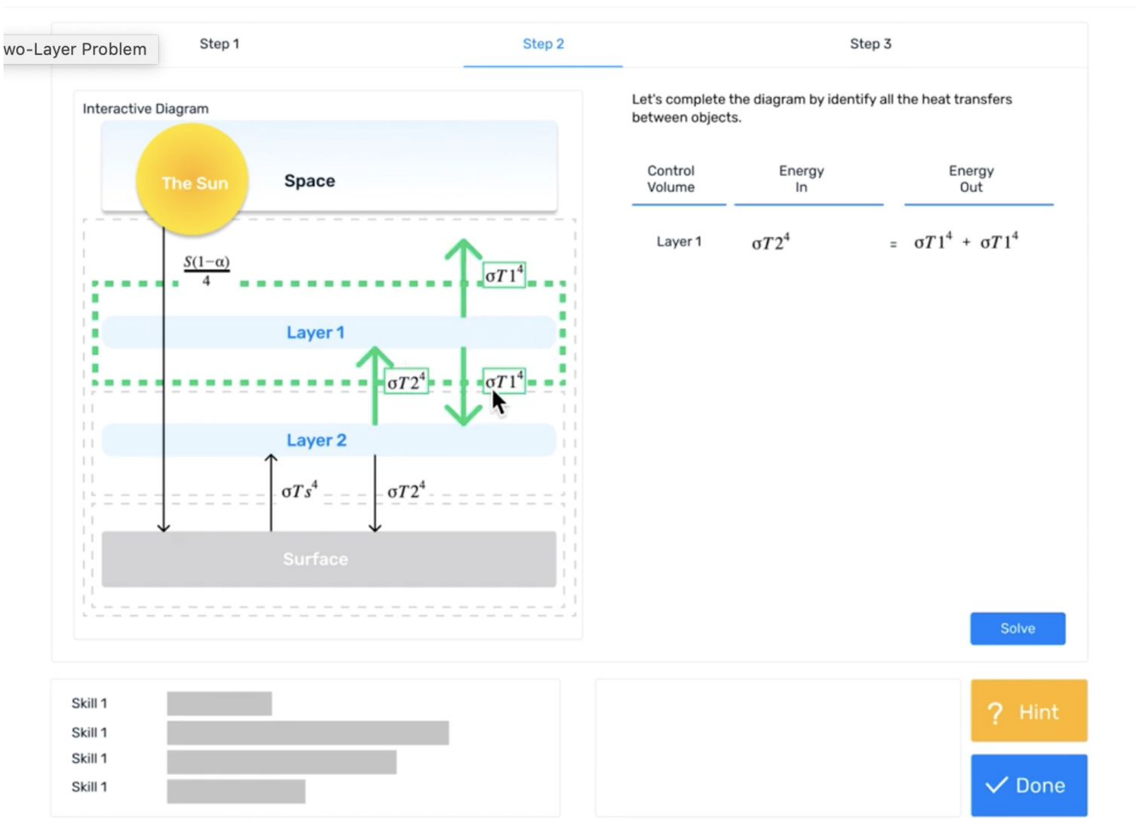
- Separated diagram and table may cause split attention
- The feedforward of the interface isn't clear, meaning that first-time users may not be able to spot all the interactable areas such as the arrows.

Reflection

- Step 1 not covering KC 2.1: does not test the students' understanding of whether they have an account for all the arrows or not.
- Step 2 the control volume is completely given to the students
- Breaking the three steps into tabs might help with managing visual complexity

Rule-Based Tutor

Video Demo: https://youtu.be/CAucp4D31pA



Feedback

- Buggy message of why sun to layer 2 isn't correct could be used to provide a more detailed explanation
    - Consider how students will learn this otherwise
    - Consider if these simplified model assumptions are important learning goals
- Consider whether there is value for the students to practice the tutor multiple times
- Any teaching? E.g. what if the students don't understand what's a control volume is

Reflection

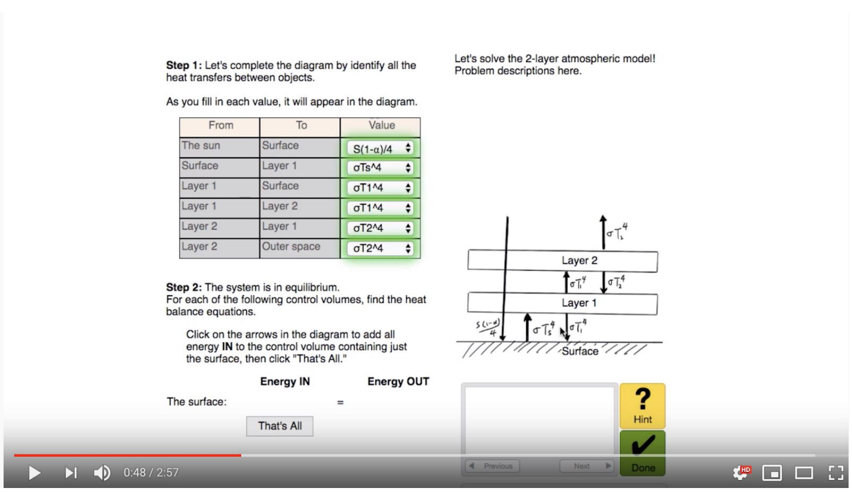
- Alter the diagram so the concept of energy pass-through and transfer is more clear
- For “why energy from the sun passes through the atmosphere” we assume that students have built up the prior knowledge of explaining this question from practicing with the no layer to 1-layer tutor.
- Add buggy messages and hint messages with detailed explanation

Final Tutors

In the submitted tutor files, the example tracing tutor model file is “two-layer.brd” with the interface file “two_layer.html”. The rule-based tutor is “twolayer.nools” with interface file “twolayer_rulebased.html”.

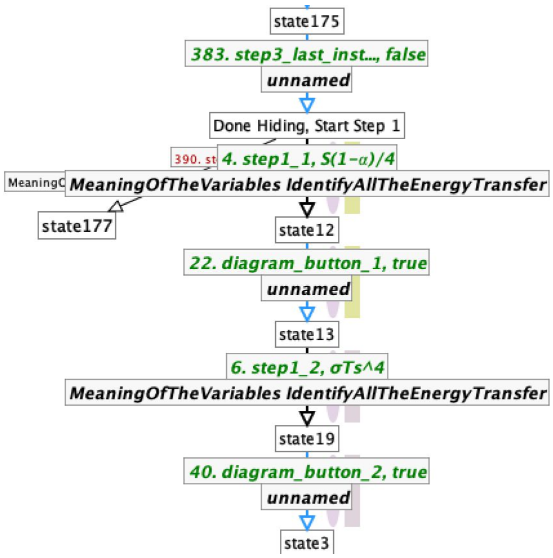
Example Tracing Tutor

(https://www.youtube.com/watch?v=uYQsBCIRapQ&feature=youtu.be)

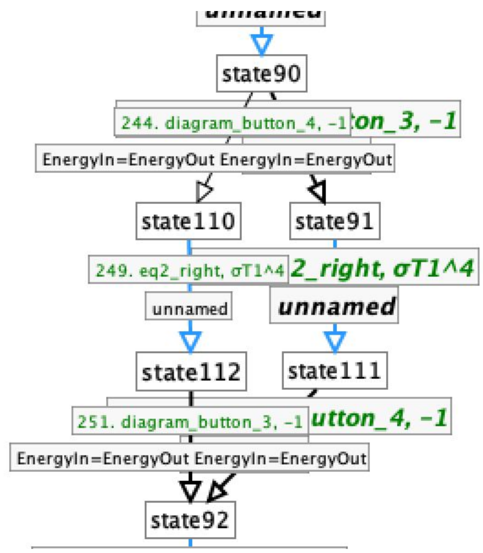


Behavioral Graph

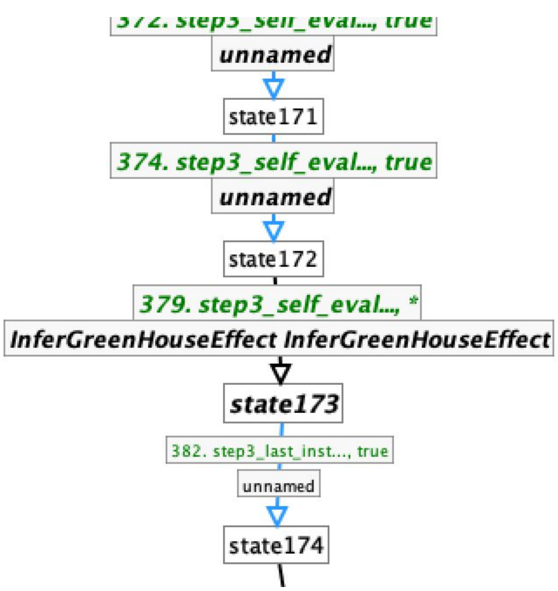
KC 2.2 Meaning of the variables.

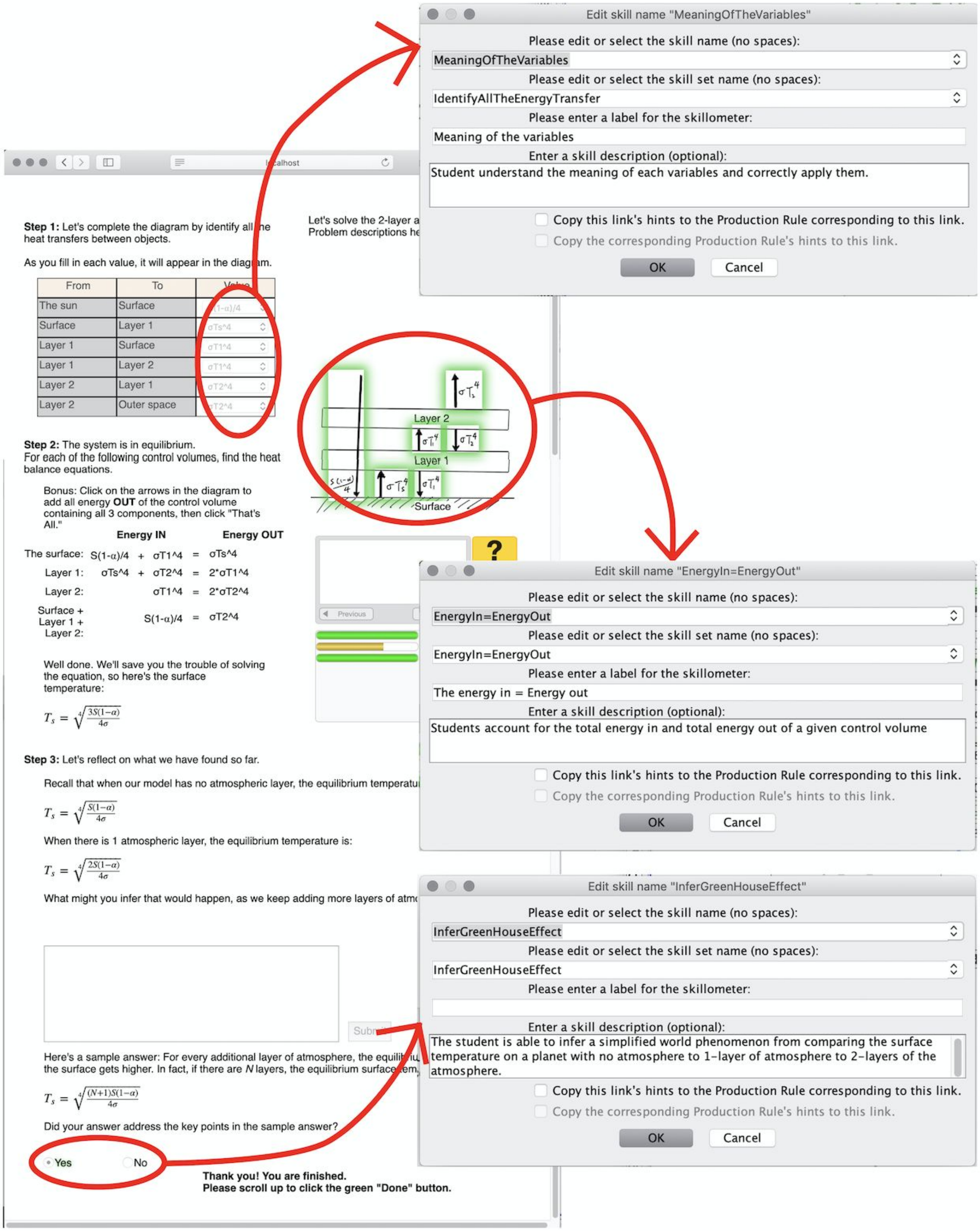


KC 3.2 The energy in = Energy out



KC 1: The student is able to infer a simplified world phenomenon from comparing the surface temperature on a planet with no atmosphere to 1-layer of atmosphere to 2-layers of the atmosphere.





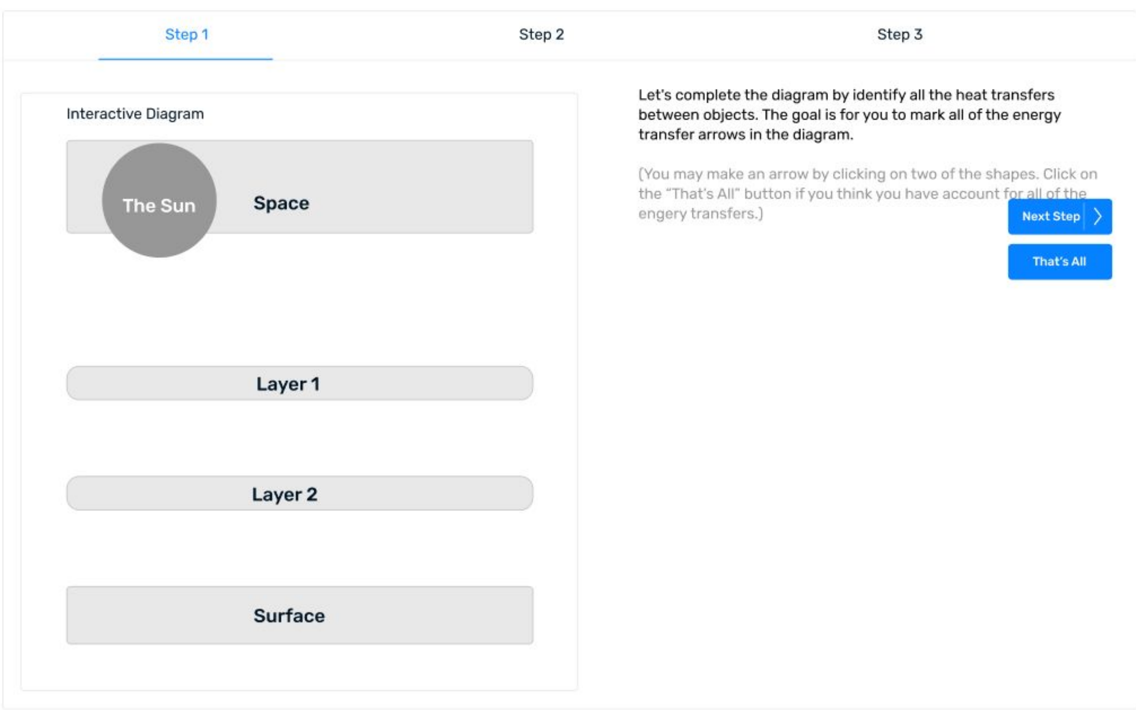
Edit skill name "MeaningOfTheVariables"
Please edit or select the skill name (no spaces):
MeaningOfTheVariables
Please edit or select the skill set name (no spaces):
IdentifyAllTheEnergyTransfer
Please enter a label for the skillometer:
Meaning of the variables
Enter a skill description (optional):
Student understand the meaning of each variables and correctly apply them.
Copy this link's hints to the Production Rule corresponding to this link.
Copy the corresponding Production Rule's hints to this link.
OK
Cancel
localhost
Step 1: Let's complete the diagram by identify all the heat transfers between objects.
As you fill in each value, it will appear in the diagram.
From
To
Value
The sun
Surface
Surface
Layer 1
Layer 1
Surface
Layer 1
Layer 2
Layer 2
Layer 1
Layer 2
Outer space
Let's solve the 2-layer a
Problem descriptions he
Layer 2
Layer 1
Surface
Step 2: The system is in equilibrium.
For each of the following control volumes, find the heat balance equations.
Bonus: Click on the arrows in the diagram to add all energy OUT of the control volume containing all 3 components, then click "That's All."
Energy IN
Energy OUT
The surface: S(1-α)/4 + σT1^4 = σTs^4
Layer 1: σTs^4 + σT2^4 = 2*σT1^4
Layer 2: σT1^4 = 2*σT2^4
Surface + Layer 1 + Layer 2: S(1-α)/4 = σT2^4
Well done. We'll save you the trouble of solving the equation, so here's the surface temperature:
$T_s = \sqrt[4]{\frac{3S(1-\alpha)}{4\sigma}}$
Step 3: Let's reflect on what we have found so far.
Recall that when our model has no atmospheric layer, the equilibrium temperatu
$T_s = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}}$
When there is 1 atmospheric layer, the equilibrium temperature is:
$T_s = \sqrt[4]{\frac{2S(1-\alpha)}{4\sigma}}$
What might you infer that would happen, as we keep adding more layers of atmo
Here's a sample answer: For every additional layer of atmosphere, the equilibriu
the surface gets higher. In fact, if there are N layers, the equilibrium surface tem
$T_s = \sqrt[4]{\frac{(N+1)S(1-\alpha)}{4\sigma}}$
Did your answer address the key points in the sample answer?
Yes
No
Thank you! You are finished.
Please scroll up to click the green "Done" button.
?
Previous
Edit skill name "EnergyIn=EnergyOut"
Please edit or select the skill name (no spaces):
EnergyIn=EnergyOut
Please edit or select the skill set name (no spaces):
EnergyIn=EnergyOut
Please enter a label for the skillometer:
The energy in = Energy out
Enter a skill description (optional):
Students account for the total energy in and total energy out of a given control volume
Copy this link's hints to the Production Rule corresponding to this link.
Copy the corresponding Production Rule's hints to this link.
OK
Cancel
Edit skill name "InferGreenHouseEffect"
Please edit or select the skill name (no spaces):
InferGreenHouseEffect
Please edit or select the skill set name (no spaces):
InferGreenHouseEffect
Please enter a label for the skillometer:
Enter a skill description (optional):
The student is able to infer a simplified world phenomenon from comparing the surface temperature on a planet with no atmosphere to 1-layer of atmosphere to 2-layers of the atmosphere.
Copy this link's hints to the Production Rule corresponding to this link.
Copy the corresponding Production Rule's hints to this link.
OK
Cancel

Rule-Based Tutor

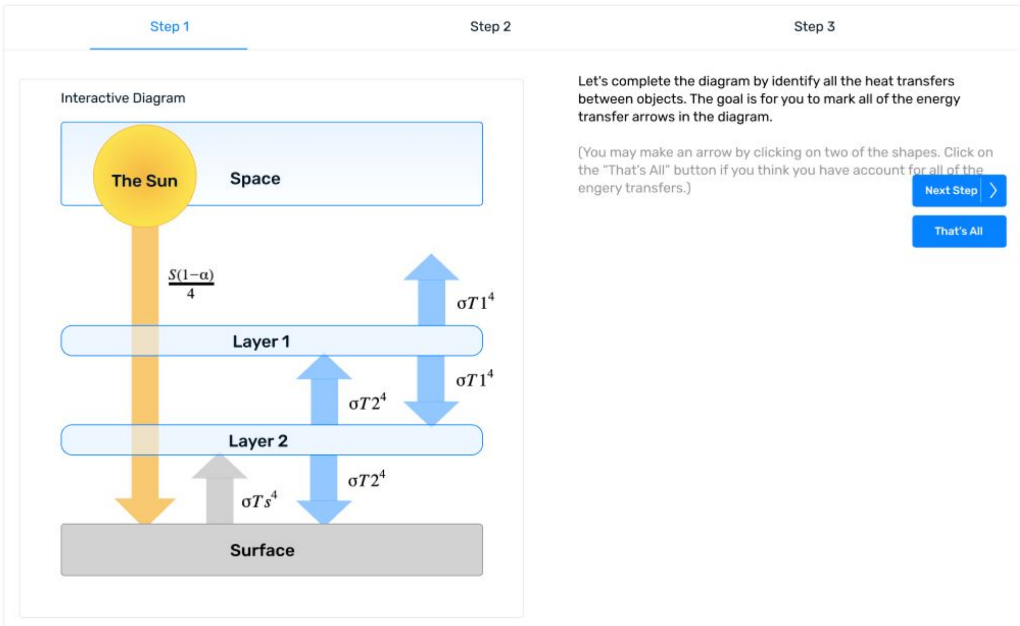
The rule-based tutor incorporates a completely new interface design that addresses many of the previous feedback. The layout of the tutor minimizes student's cognitive load caused by scrolling the page for hint and error messages. A progress bar is provided on top of the problem-solving area for students' reference. The interface design adopts a more accurate diagram with a representation of how the energy transfer and pass through layers of atmosphere. For step 1, all the interactions can be done on the diagram. For step 2, more functionality of interaction is provided for the students.

Step 1 prototype:

To reduce the cognitive load that may be caused by split attention, we designed step1 as it allows the student to complete tasks on the interactive diagram. We also addressed the issue of unclear feedforward by placing detailed instructions on the right side of the tutor interface.

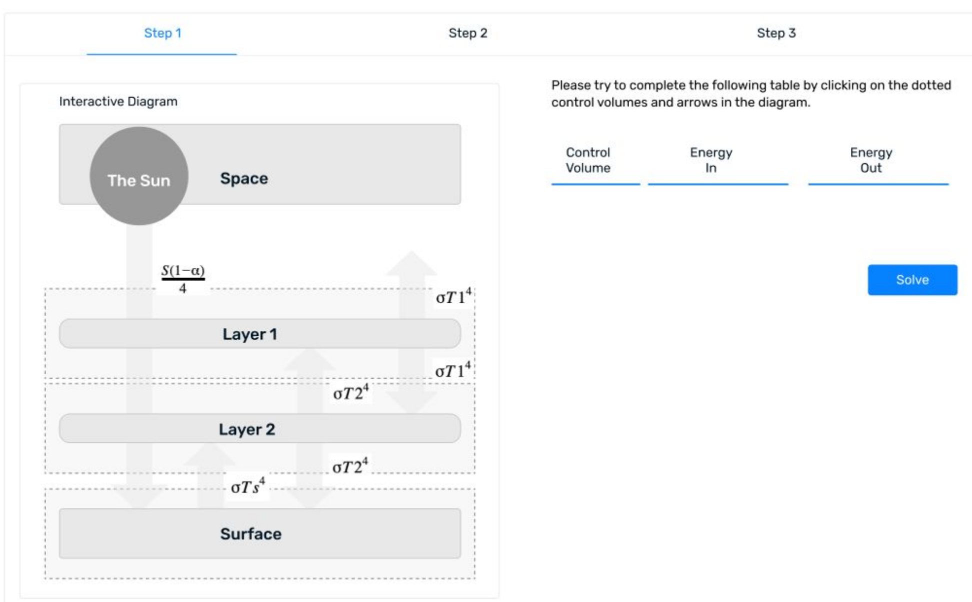


Step 1 buttons fully activated.

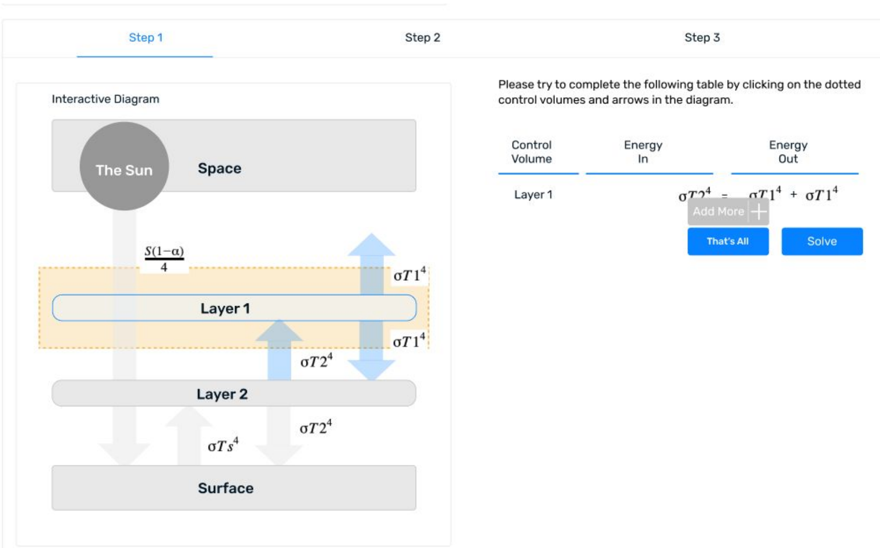


Step 2 prototype:

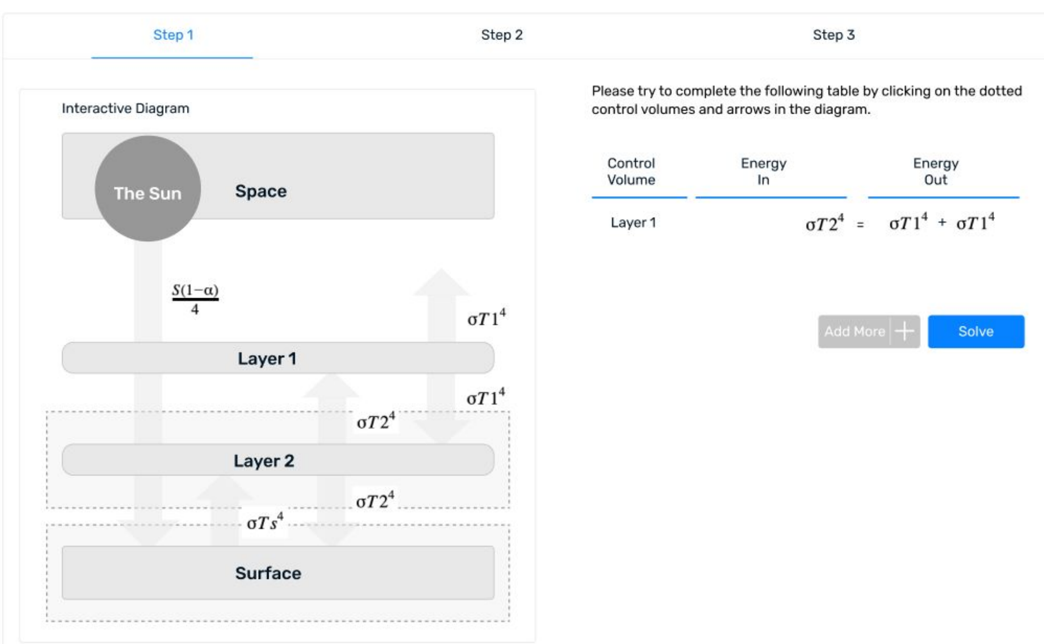
The student starts, from following the instruction on the top right, select a control volume bo on the diagram.



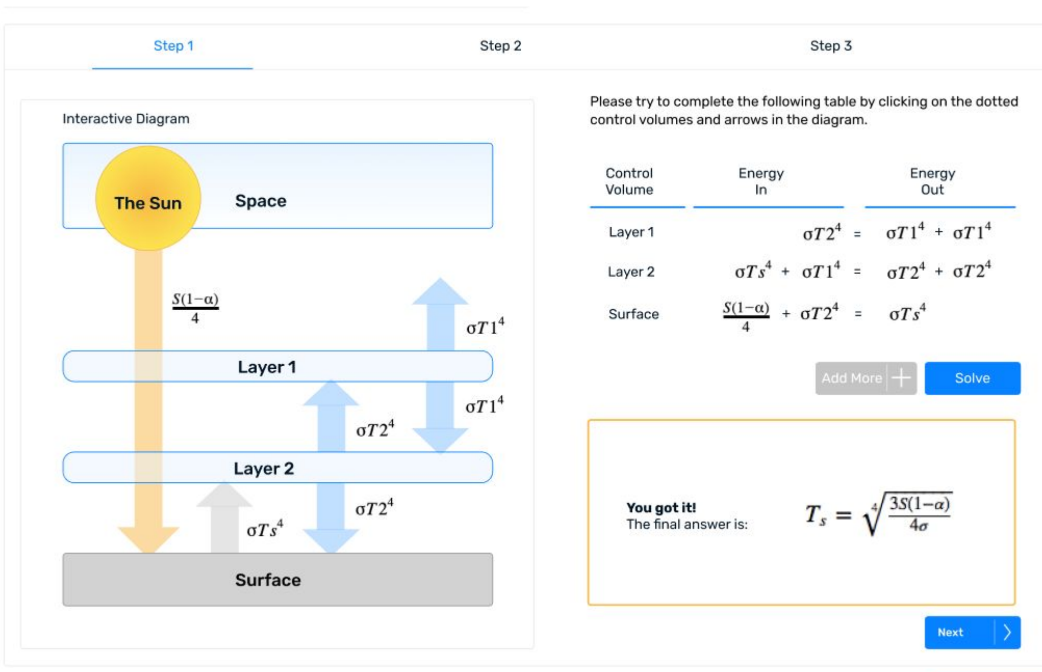
As the control volume been selected the color will change and other boxes are made disappear to reduce cognitive load. The student then can click on arrows and see the variables appear on the table.



The student finishes filling out the table and optionally clicks on the “add more” button to proceed to another control volume. If the student does account for all of the arrows, the rest of the control volume boxes appear on the diagram for selection.

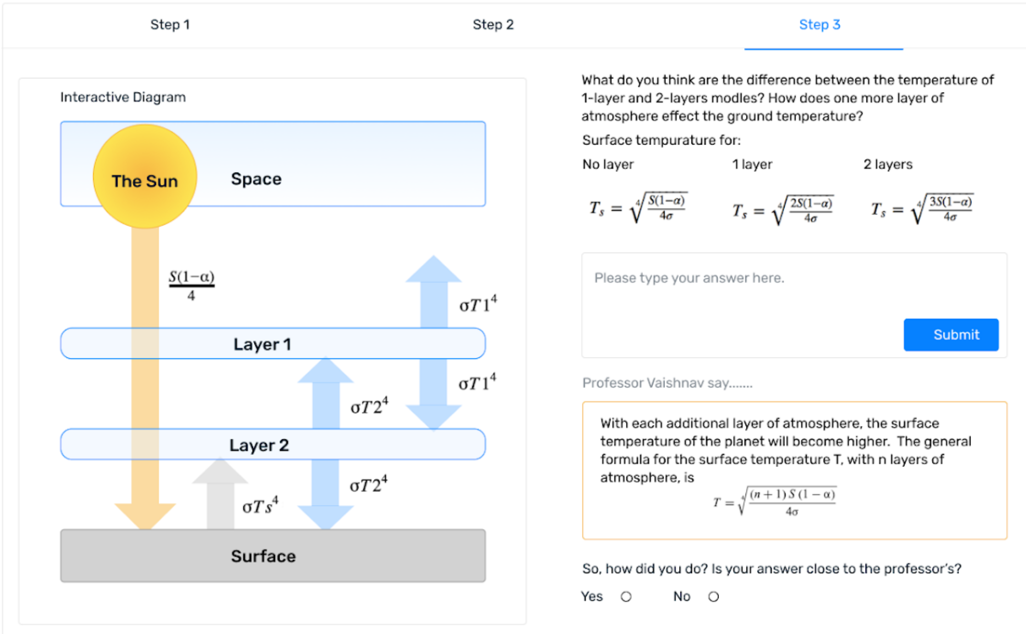


The final answer will be presented to the students as he/she finishes a sufficient amount of equations and click on the "solve" button.



Step 3 prototype:

The student is asked to infer from the surface temperature for no layer, 1-layer, and 2-layers of atmosphere. An example answer is presented after the student submits his/her answer. The student finally is asked self-assess and submit feedback to the tutor.



Future Plan

Unfortunately, the rule-based tutor is still incomplete. It is currently functional up to part of Step 2.

We plan to continue the work in hopes of presenting Professor Vaishnav something that can potentially benefit his students. To do that, we will keep implementing the rule-based tutor up to Step 3 over the break, and present the tutors to Professor Vaishnav for feedback and refinement.

We may implement some improvements to the tutor based on the presentation feedback in the future. Some of the possible refinements include:

- More complete explanations and instructions in the error step messages and hints

- Ask students about model details that they may not see unless an error step is performed
- Reduce the level of scaffolding in Step 2
- Refine the directions and interface design as we bring the tutor to test with more students

Future development will be updated to the following repository:

https://github.com/es2mac/TwoLayerAtmosphericModel/

Appendix

Research Planning

Type	Methods	Questions
Primary research	Interview, CTA, Self-test	1. Who are the targeted learners? 2. What are the expected learning outcomes? a. What are the knowledge components that students are expected to understand as an outcome of using the tutor? b. How should the tutor assist students to reach those outcomes? 3. Some example questions that may appear on the tutor?

		a. What steps does an expert take solving the example question? b. What knowledge are involved in conducting these steps? 4. Where in the curriculum is the intellectual tutor posits (e.g. at the end of each lecture? Mid-term assessment?) a. When in relation to each lecture is the tutor assigned to the students (before, during, or after class)? 5. Why use the intellectual tutor?
Secondary research	Slides, Textbooks	1. What is the greenhouse effect? 2. What causes temperature uprising. 3. What are the knowledge components? 4. What are some examples of questions?

Initial Knowledge Components

#	**Knowledge Component**	**Note**
1	The student is able to infer real-world phenomenon from comparing the surface temperature on a planet with no atmosphere to 1-layer of atmosphere to 2-layers of atmospheres.	Difficult

2	Given solar constant S, albedo, surface temperature Ts, the temperature of first & second-atmosphere layers T1 and T2. The student is able to calculate the surface temperature Ts. With provided Blackbody emission and solar energy absorbed functions.	
3	A layer of atmosphere has two surfaces.	
4	Energy balance: energy in = energy out	Difficult

Research Findings and Insights

Research questions	**Methods**	**Answer**	**Insight**
Who are the targeted learners?	Interview	Professor Vishnarv's students in the graduate level Climate Change Science and Adaptation class.	- Students have an undergraduate level of prior knowledge in physics, less tutoring on physics is required (student may know energy balance).
What is the expected learning outcome?	Interview	Students understand and able to explain the greenhouse effect.	- Guide the students understand the formulas with tasks

			- Use short answer questions - Use simulation - Ask students to explain the formulas - Demonstrate how formula derives - The tutor does the calculation for students
What are the knowledge components?	Interview (professor and students)	(See section knowledge components below)	- Assign more practice tasks on the difficult knowledge components - A way to collect evidence of the student's reasoning process when doing each task.
How should the tutor assist students to reach those outcomes?		Help students further understand the lecture content.	- No need for in-depth instruction. - Remind the students of the class content (difficult KC > normal KC) - Provide more worked examples that allow the student to apply the knowledge into various contexts.

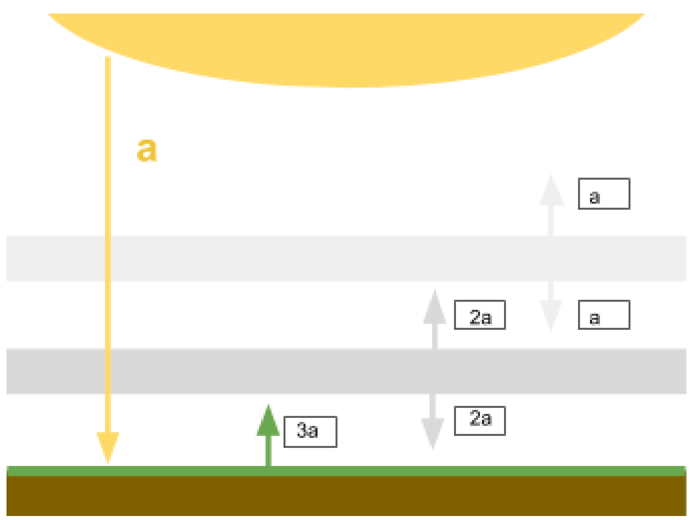
Example questions?	Interview, textbook	(See textbook questions below)	- (DKC) Control volume is what the professor emphasizes, but students don't really know of
To what extent should the students understand the knowledge?	Interview	Students should understand how more layers of atmosphere causes an increase in temperature under a simplified model.	- (Change KC) Question students for solving a task under a simplified model
The rubric of criteria to evaluate student's understanding based on their reasoning steps?	Interview		- No need to test the students' equation solving skills (no need to address equation solving and have the tutor solve for the students
Where in the curriculum is the intellectual tutor posits (e.g. at the end of each lecture? Mid-term assessment?)	Interview	After a video lecture and before the midterm exam.	- Students have prior knowledge to the KCs - Minimize the instructions and only scaffold the identified difficult knowledge components

Why use the intellectual tutor?	Interview	Supplement the lecture. Assess students' understanding.	- Write buggy rules for common misconceptions - Provide further explanation in the buggy messages

Low-fi artifact brought to interviewing professor Vaishnav

Step1: Student input variables.

KC: 2.1, 2.2



Step2: Student convert energy per unit into temperature

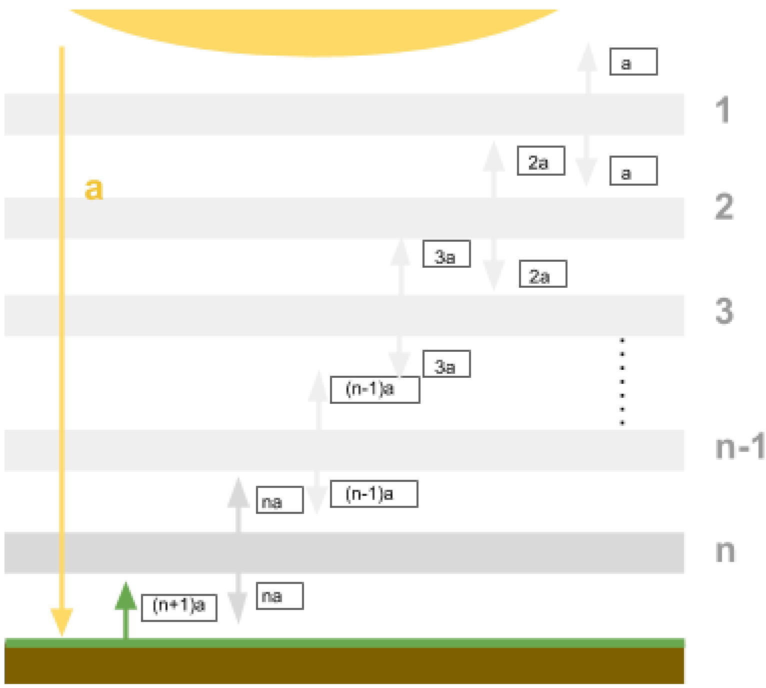
KC:

$$3a = \frac{S(1-\alpha)}{4} = \sigma T^4$$

$$T = \sqrt[4]{\boxed{}\frac{S(1-\alpha)}{4\sigma}}$$

Step4: Student input variables.

KC:



Step5: Student makes the general formula

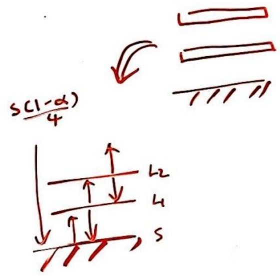
KC:

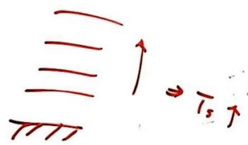
$$(n+1)\,a = \frac{S\,(1-\alpha)}{4} = \sigma T^4$$

$$T = \sqrt[4]{\boxed{\quad}\,\frac{S\,(1-\alpha)}{4\sigma}}$$

Example Tracing Tutor

Wireframe





Task(s) : – Solve for T_s in 2-Layer

– multi-layer

– Inference/explanation

A) Identify transfers

From	To	Value
Sun	S	$\frac{S(1-\alpha)}{4}$
S	L_1	σT_s^4
L_1	S	σT_1^4
L_1	L_2	σT_1^4
L_2	L_1	σT_2^4
L_2	Space	σT_2^4

B) Equations for each control volume

	Control Volume	In	= Out
b1)	S	$\frac{S(1-\alpha)}{4} + \sigma T_1^4$	$= \sigma T_s^4$
b2)	L_1	$\sigma T_s^4 + \sigma T_2^4$	$= \sigma T_1^4 + \sigma T_1^4$
b3)	L_2	σT_1^4	$= \sigma T_2^4 + \sigma T_2^4$
b4)	$S + L_1 + L_2$	$\frac{S(1-\alpha)}{4}$	$= \sigma T_2^4$

c) Solve for $\boxed{T_s}$

Approach 1: using b1, b2, b3 (Vaishnav)

Approach 2: using b4, b3, b1 (Easier)

Approach 3: using b4, b3, b2 (Not encountered but should work)

Approach 4: using b4, b2, b1 (Theoretically ok but weird)

$\Downarrow$

Get $\sigma T_s^4 = 3 \cdot \frac{S(1-\alpha)}{4}$

S $T_s = \sqrt[4]{\frac{3S(1-\alpha)}{4\sigma}}$ //

Key points:

- System can be understood by a few basic rules / very basic simplified model
  - Energy radiated (assuming perfect black body):

→ σT^4

  - Control volume equilibrium:

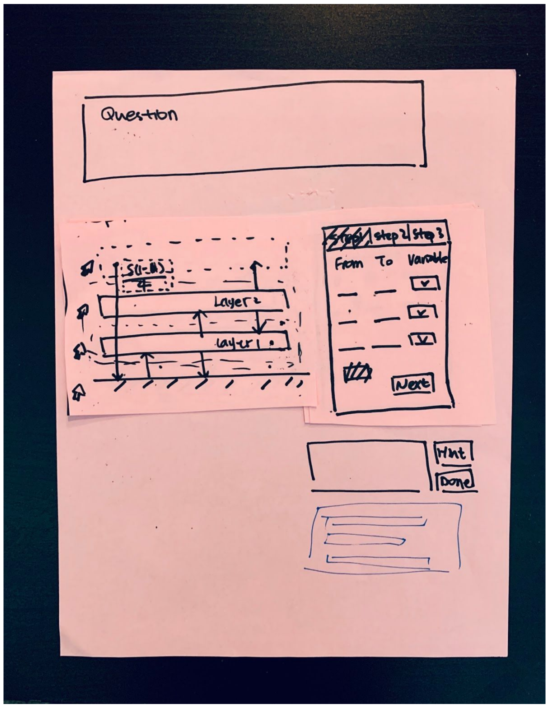
→ Total energy in = energy out

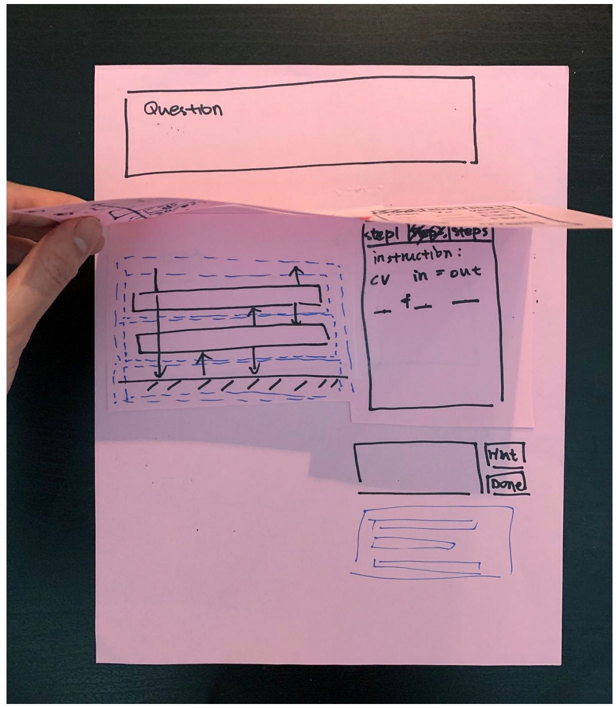
- Adding atmospheric layer ⇒ higher T_s

From	To	value
surface	L1	σT_s^4

Rule-base Tutor

Wireframes





Hi-fi Prototype_iteration 0

(https://youtu.be/gvqvB70bd0w)

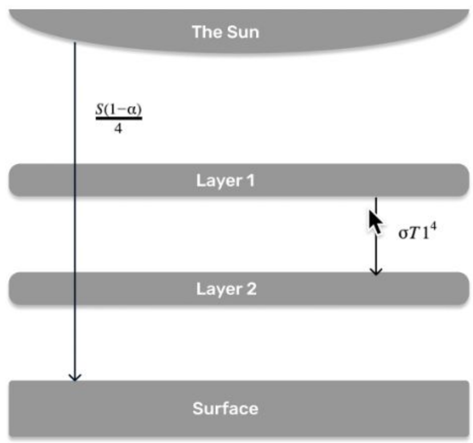
Step 1

Step 2

Step 3

Let's complete the diagram by identify all the heat transfers between objects.

Interactive Diagram



That's All

Skill 1

Skill 1

Skill 1

Skill 1

? Hint

Done