Expert Reasoning about Independent and Dependent Variables in Thermodynamics

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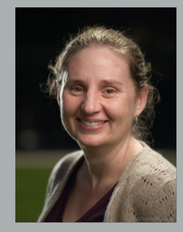

Research Questions

We interviewed five physics faculty who are experts in thermodynamic to answer the following questions:

RQ1 **How do experts determine if a variable is independent in a thermodynamic system?**

RQ2 **How do experts match a thermodynamic potential and a physical system?**

Results will help us contextualize student statements in our ongoing investigation [1] of student reasoning about independent variables in thermodynamics.

Interview Protocol

General Questions

Q1	What is a thermodynamic potential?
Q2	What role do thermodynamic potentials play in thermodynamics?
Q3	What are Legendre transformations?
Q4	What steps do you take to match thermodynamic potentials and physical scenarios?

Specific Scenarios

Q5 You want to learn as much as possible about 3 scenarios. For each:

- What is your system?
- What experiments could you do?
- What would the independent variables be?

Gas	A heavier-than-air gas in an open container.
Ice	A sturdy, sealed metal box filled with ice that you put in a heat bath.
Comet	A rocky comet that you shine a laser at.
300K	(Follow-up) You heat the comet to 300K.

Statement Deconstruction

We used a multidimensional open-coding scheme that we call Statement Deconstruction. Text excerpts are broken into statements that are then coded according to a claim and justification. For example, the following exchange between the interviewer and Danny has been coded in the table to the far right:

Interviewer: *What steps do you take to match a thermodynamic potential with a physical scenario?*

Danny: *You look for independent and dependent variables. So you look for variables that you can either set, so I give it a certain value, or control that it doesn't change.... So those you say those are controlled variables, those are the independent variables.*

Claim	Claim Object	Justification Object	Justification*	Justification Category*
selects	thermo. potential	which variable	is independent	Other
Ind Var is	variable	variable	we (can) control	Control
Ind Var is	variable	variable	we keep fixed/constant	Control + Change

*In this poster, we primarily look at the categories of Justifications that our experts used.

Justification Categories (78 Statements)

Control 21

A large portion of expert statements conveyed the importance of being able to control variables in order to consider them independent or important for selecting an appropriate thermodynamic potential.

Interviewer: *Would you consider temperature to be an independent variable in that case?*
Blair: *Yeah, because that's what you control.*

Emerson: *One [independent variable] is the laser power...the dependent variable will be the temperature, so I can increase the laser power and that will increase the temperature accordingly.*

Change 12

Experts often explicitly talked about the change (or lack of change) of a variable as being a good indicator of independence or of which thermodynamic potential they should select.

Avery: *You have to assess a problem and determine which variables are being changed and then transform to the correct variable...and find the right free energy- Legendre transform.*

Measurability 8

The ability to measure a variable was not clearly associated with independence or thermodynamic potentials. Charlie even offers two seemingly contradictory statements at different points of the interview:

Charlie: *Temperature is an easy thing to measure, so I should treat that as my [independent] variable.*

Charlie: *Volume is going to be held fixed, so I'll think of temperature and volume as my two independent variables. I'm going to measure pressure.*

Functional Relationship 5

Some statements indicated that knowing how a variable relates to others in the system would allow the expert to treat the variable as independent or select a desirable thermodynamic potential.

Danny: *What is the pressure at different levels?... You can also partition it in sort of volumes. I need the equation of state, [then] they both work.*

Other 7

Some statements did not fit into any other category,

Danny: *So you look for independent and dependent variables.*

Charlie: *What I do is I always think about what I want the independent variables to be.*

Charlie: *We are free to think of whatever we like as independent variables.*

Conclusions

What experts say vs. what they do

In discussing general cases, experts primarily talked about the Control that they have over the physical scenario, (which is consistent with the literature [2]) and Change. However, when discussing specific scenarios, experts also discussed Measurability and Functional Relationship.

Change is at the center of expert reasoning

Some justification codes, such as the "we keep constant/ fixed," code shown in Statement Deconstruction, fell into more than one justification category. For all such codes, Change was one of the Categories, as can be seen in Justification Categories. In these cases (25 statements), the non-Change categories can be considered different ways of knowing the value of a variable (or its change).

Experts have a wealth of strategies for finding Change

The previous two results suggests that the tools and strategies that experts have for finding the value of a variable (or its change) are varied and sophisticated, but that these tools and strategies may not always be conveyed to, for example, students.

The key is knowing how a variable changes

Overall, 62 of the 78 statements suggest that experts believe they can select an independent variable or thermodynamic potential if they *know how a variable changes*. This suggests that physics instruction should emphasize that knowing how a variable changes, *regardless of the size of the change or how it is known*, allows that variable to be treated as independent.

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References

[1] M. Vignal, C. Manogue, D. Roundy, and E. Gire, in *Physics Education Research Conference 2017*, PER Conference (Cincinnati, OH, 2017) pp. 404–407.

[2] R. K. Zia, E. F. Redish, and S. R. McKay, Am. J. Phys. 77, 614 (2009).