DO STRUCTURE MAPS FACILITATE EXPERT-LIKE PROBLEM SOLVING STRATEGIES IN PHYSICS?

The overarching goal of this study was to explore whether the use of expert-designed structure maps can facilitate expert-like problem solving strategies by students in physics. We explore the use of structure maps by students in an algebra-based physics course and the evolution of these maps based upon students' feedback collected over one semester. The participants were trained to use structure maps while solving problems sharing similar deep-structure elements. They met for one hour every week to work on the problems using the maps. We report here on the ways in which students used the structure maps during the interviews, the difficulties faced by students as they attempted to use these maps, and the feedback offered by students regarding the maps. We also report on how we changed the maps based on feedback from the students and to facilitate their use during problem solving.

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Introduction

Educators have long valued the development of problem solving skills in all science, technology, engineering, and mathematics (STEM) disciplines including physics. Research has shown that most students tend to resort to novice 'means-ends' analysis and equation-based strategies while solving problems in physics (Hsu, Brewe, Foster, & Harper, 2004; Jonassen, 2000). Educators have long struggled with developing strategies that wean students away from these novice approaches and facilitate students' use of expert-like problem solving strategies.

Research has shown that students' use of concept maps across several methodological features and instructional conditions was associated with increased knowledge retention (Nesbit & Adescope, 2006). Previous investigations have also reported that over the long term students can acquire procedural automation of concept mapping and assimilate it into their problem-solving repertoire (Ericsson, Krampe, & Tesch-Romer, 1993; Novak, Gowin, & Johansen, 1983). We report here on a semester-long treatment of using structure maps in an introductory algebra-based physics course. Our objective was to gauge how students react to these structure maps and how the maps evolve to meet students' needs. We addressed these research questions (RQ):

RQ #1) How do students use expert-designed structure maps to solve problems and what difficulties do they experience while using these maps?

RQ #2) How do the maps evolve in response to feedback provide to the experts by the students?

Methodology

Twelve student volunteers enrolled in algebra-based physics were randomly selected from 46 volunteers. Two groups of six students were formed based upon student schedules. These 12 participants met in their respective groups a total of nine times during the semester. One of the 12 volunteers selected dropped the class prior to the completion of the study.

The two groups of six and five students met each week for one hour. For the first two weeks of the semester, one of two moderators would hand out a set of four similar deep-structure problems for students to work on briefly. The selected problems were often modified variations of problems asked in *Physics: Principles with Applications*, Giancoli, 6th Edition. All four problems for each week would inherently cover the same basic physical concept studied recently in the course. Distinct differences between problems in the set are surface feature and/or complexity dependent, and the sequence at which these four problem types are delivered remains the same throughout the treatment. Problem 1 and problem 2 remain similar in terms of surface and deep-structure, but the quantity that students are asked to solve for in problem 1 will replace a quantity previously given in the problem statement. See Figure 1 below for examples corresponding to the four problem sequence. Problem 3 remains structurally similar to problem 1 and problem 2, but the surface features are different. Problem 4 adds complexity to the problem by requiring students to utilize previously studied concepts or principles in addition to the primary concept. These types of problem sequences are based upon work done by Nokes and Ross (2007).

Problem 1	Problem 2
A sled is initially given a shove up a frictionless 30.0 degree incline. It reaches a maximum vertical height 1.35 m higher than where it started. What was its initial speed?	A sled is initially given a shove up a frictionless 30.0 degree incline. It has an initial speed of 6.0 m/s. What will be the maximum change in vertical height acquired by the sled?
Problem 3	**Problem 4**
A medieval archer fires an arrow at an upward angle of 80 degrees from the bottom of a 265 meter wall. Assuming that the archer barely clears the top of the wall, what would be the required initial arrow speed?	A vertical spring whose spring stiffness constant is 950 n/m, is attached to a table and is compressed down 0.20 m. To what height above its original position (spring compressed) will a 3.0 kg ball fly?

Figure 1. Top Left: Problem 1 from week 6. Top Right: Problem 2 from week 6. Bottom Left: Problem 3 from week 6. Bottom Right: Problem 4 from week 6. Problems above are variations of problems asked in Chapters 6 of *Physics: Principles with Applications*, Giancoli, 6th Edition.

In the third week students were introduced to structure maps for a given section of the textbook. A structure map is best described as a representation expressing functional interdependency between concepts and quantities (Gentner, 1983; Novak et al., 1983). Gentners' Structure Mapping Theory describes mapping as a cognitive function, or a set of interpreted implicit restraints maintained by an individual. For this project we externalize Gentners' representation as a modified form of a concept map. These visual structure maps are created by two experts knowledgeable in physics education. See Figure 2 for examples of structure maps used in the first half of the semester. The nodes contain quantities and are connected to each other in one of two ways: by their sidewalls or by arrows. When connected by their sidewalls, we aim to represent a specific association between quantities that may be written as an equation. In cases where equations may radically change depending upon the context of the problem (e.g., there is no change in kinetic energy), the arrows are placed between nodes to represent a more general association between quantities.

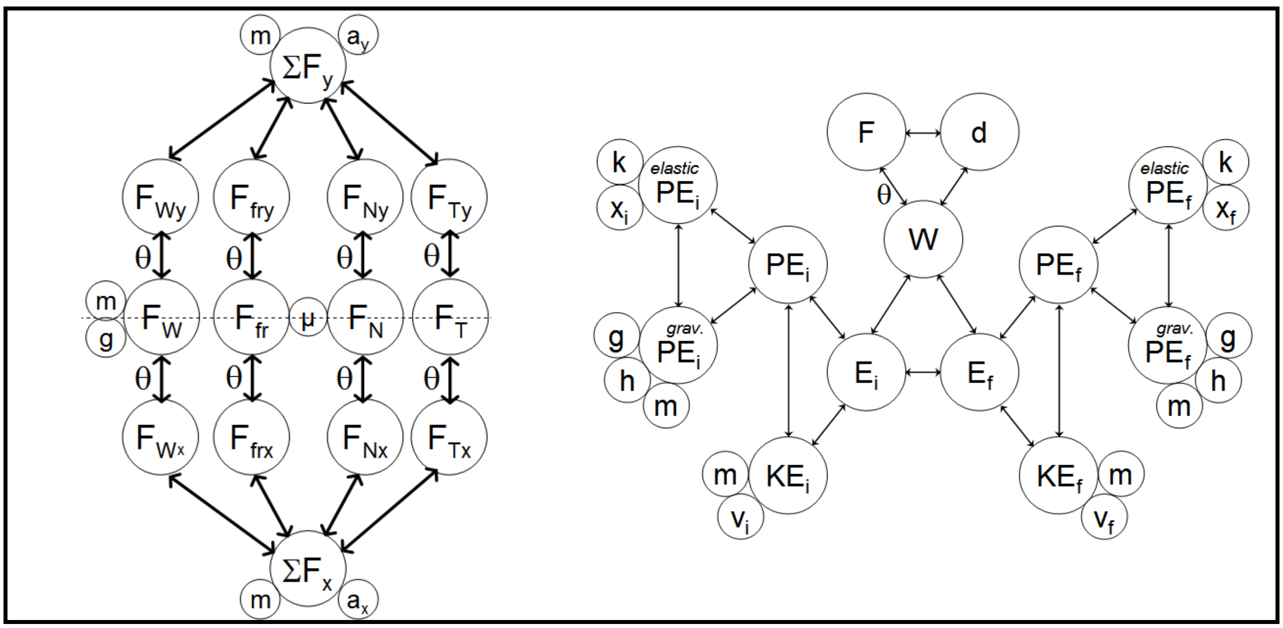

Figure 2. Left: A structure map used during week 4. Right: A structure map used during week 6. Problems selected for students to work on while using these maps were variations of problems asked in Chapters 4 and 6 of *Physics: Principles with Applications*, Giancoli, 6th Edition, respectively.

Students were initially trained to use the structure map handed out by the moderator by marking 'X's of varying colors through quantities that are given in a problem, the quantity that is asked for in the problem and quantities that must be calculated in order to progress from the given quantities to those asked for in the problem. Students were allowed to use the same printed map for all four problems given during the interview, but often students opted to take a new printout for each problem. Both treatment groups were given the same instructional PowerPoint slideshow complete with an example problem and marked structure map. As the semester progressed, they were given time to use the map in their own way and assistance was provided only when participants were unable to help one another. Students were asked to react to the structure maps and discuss elements of the map they found useful. Participants would sometimes be asked to present their structure maps and problem solutions to the group if they were quiet for too long.

For the remaining three weeks of group interviews, participants were again asked to use structure maps while solving problems, but the maps were restructured to accommodate some of the students' suggestions. Structure maps used for the rest of the semester became visual representations of equations and the relationships between quantities within equations for a given section of the textbook. (See Figure 3 for the map used during week 9.) At the end of the group interviews, students were asked to explain how they felt about the new maps and discuss the features they found most useful.

Results and Discussion

For the purposes of this report, results will focus on three group interviews. Each group interview described below highlights the significant changes in the student-student and student-moderator exchange about the structure maps. These interviews were conducted on the fourth, sixth, and ninth weeks of the semester. To probe students' reactions and use of the structure maps, each student was asked the same two questions at the end of each group interview and any necessary follow-up questions such as "How did you like the map?" and "How did you use the map?"

Week 4

During week 4, the structure map shown on the left of Figure 2 was introduced to students covering dynamics and Newton's laws. Only one of the six students in group 1 stated they found the map useful. This student believed the map organized information from the problem statement so that connections between quantities could be readily seen.

> *G1S2: I do like the concept map because there are some equations involved in physics that it's just like, when you need that and how do you use it and why and kind of I don't know, just organizes it better so that you can look at what connects with what.*

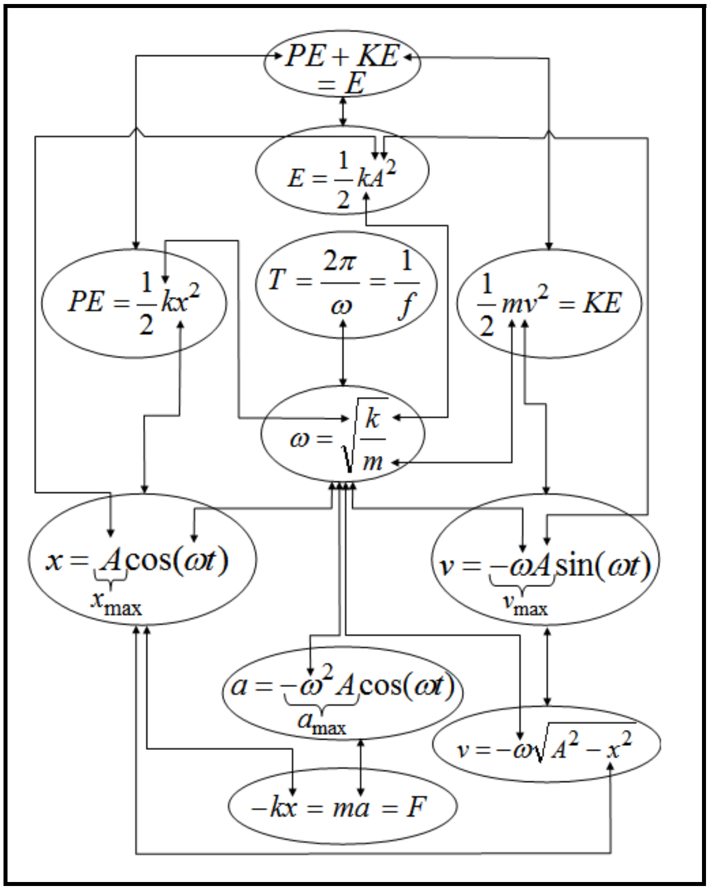

Figure 3. A structure map used during week 9. Problems selected for students to work on while using this map were variations of problems asked in Chapter 11 of *Physics: Principles with Applications.*

One of the five students in the second group did not use the map while solving problems simply because he felt he did not need any assistance with solving any of the four problems. Of the remaining four students in the second group, only one felt the map was helpful while solving the problems. This student responded that it helped her keep track of the information given and information she was looking for.

Most students in both groups voiced a concern that the map was hard to follow. Some were more specific in stating that not all of the information needed could be displayed on the map while others agreed. One student (G2S3) stated: "I don't know how to mark it on here exactly. Like, I couldn't figure out how to relate like the terms on here to the problem."

Two students, one from each group, also felt that the map was difficult to use without an equation sheet nearby. Most other students within both groups agreed with this claim as well.

A similar force map was given in week 5 which included centripetal acceleration. Students were given the option to modify it on the spot, but often felt no desire to salvage any part of the map. The map, similar to week 4, was disliked. Students used the map only when they were reminded to do so by the facilitators.

Week 6

During week 6, the structure map shown on the right of Figure 1 was introduced to students covering work and energy. The map's physical layout was similar to maps previously used, but because this map covered work and energy, there was a temporal symmetry to the map that was not previously available for other physics principles like kinematics or dynamics. The left side of the map contained all initial quantities and the right side contained all final quantities.

There was a significant difference in student feedback on this map compared to the previous maps. All 11 students favored the work energy map over the previous kinematics and force maps, but only 10 of 11 used the map during the interviews. When we asked each student individually about their thoughts on the structure map, the one student that did not use the map stated, "I did not need it. Why would I use it?" For future reference, I will refer to this student as G2S5.

Other participants were also asked to explain why they liked the work energy map over the previous map. A typical response is below:

> *G1S1: I feel like this one (work-energy map) you're just looking for your potential energy final, like I feel like it's just easier to focus in on that area [of the map] and how you would lead there, other than the other one (force map) that's just like you have [a quantity] down here but you feel like you have to go through all the other bubbles.*
>
> *G2S4: "Like this (force map) it's all one big thing, but for this (work energy map) you can follow along so you can go from this to get this and …like you can follow the arrows on this one."*

All other participants, with the exception of G2S5, used the map and found it easier to navigate between quantities that were given and those that were asked for in the problem. Some referred to the work energy map as being similar to a "road map." They were capable of selecting all values that were given in the problem by circling them and selecting the value that was asked for by crossing an 'X' through the value. They then established a clear path following arrows which led from the quantities given in the problem to those asked for in the problem. Though this map was better received than previous maps, students still wanted equations to be provided. Two students also stated that they would prefer to see units included with the maps. G1S3 stated, "…units, like what the units should be, like knowing what each value should have for units, so I know when I do the problem I'm not missing that."

Week 9

The structure map, shown in Figure 3, covering vibration and waves was introduced in week 7 and used up through week 9. The map contained equations in the nodes, while the arrows represented relationships between quantities within the equations. Initially the map was viewed as too complicated by some students in both groups. One student G2S3 stated: "Well I felt like I needed it in problem two…I don't know, it's just a lot of arrows…. a lot more stuff I guess. It is intimidating."

Only two students in group 1 and one student in group 2 initially used the arrows between quantities to guide them to a solution. As the session progressed, all 11 students liked the map and 10 students found the new map to be useful while solving problems. Most students liked having the equations given directly on the map. Many felt that the arrows connecting quantities across equations were very helpful.

> *G1S3: [This map is] a lot easier to use. I don't have to like look up a bunch of different equations like, oh I don't have that… you can just see how everything relates and what you have and how it works together."*

Similarly, G2S3 no longer felt the map was intimidating, determining that no arrows between quantities using similar notation was a good indication that those were not identical values. G2S5 also decided that he liked the map and used it for problem 4, but generally did not prefer using any map. Here is a small segment of the group 2 interview:

> *I: What did you think of the map after problem 4?*
>
> *G2S2: I like it.*
>
> *G2S5: Yeah.*
>
> *G2S3: Used it a lot. It's nice.*
>
> *G2S2: I might actually be putting it on my cheat sheet for the test…It's easy to understand.*
>
> *I: Okay. Were the arrows helpful?*
>
> *G2S3: Yeah, because if you didn't know what you were doing to an extent, but you know kinda what you're doing, you could be like this problem it (v) doesn't link to this (v_{max}) because your arrow isn't there. I kinda looked at it that way.*
>
> *G2S5: This is good, but can I say my personal opinion?*
>
> *I: Of course.*
>
> *G2S5: I prefer to work without maps. If you know the equation, you know the variables, then there's no need to see this thing [structure map], like that's my…I don't know.*

During this final group interview, participants made it clear that the new map would be added to their 'cheat sheet' for their final examination along with the work-energy map. The 'cheat sheet' could be any 8 ½ x 11 sheet of white paper with notes or equations written on both sides. Problem examples were not permitted.

Conclusions & Limitations

In response to RQ (research question) #1, our results indicate that students have trouble using the quantities in a structure map to solve problems if they are not provided explicit equations. Students appear to like the map to the right of Figure 2, but we do not know whether it was the map's temporal symmetry or whether the topic is just better understood by these students. A map with equations in the nodes, like Figure 3, enabled students' recognition of connections between individual quantities inside equations and was found useful by the students.

In response to RQ #2, feedback from students led us to change the structure maps from those in which the nodes contained physical quantities to those in which the nodes contained equations, with arrows showing how quantities between equations were related. These kinds of maps appeared to provide students a pathway to connect the equations and were found to be useful by the students in problem solving.

While students found the map with equations in nodes and arrows connecting quantities, like Figure 3, to be useful in problem solving, there is no evidence that these kinds of maps facilitate expert-like problem solving strategies. Rather students continue to use novice-like, equation-based problem solving strategies when provided with these maps. Therefore, this study provides no evidence that structure maps as used here facilitate expert-like problem solving in physics.

The results of our study are clearly not promising. One possible reason is that the skills for using structure maps in expert-like problem solving need to be developed over long periods of time. Our study was clearly limited in scope and the types of structure maps used. Future work with a larger experimental sample and different kinds of structure maps is needed.

Acknowledgements

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References

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Gentner, D. (1983). Structure-mapping: a theoretical framework for analogy. *Cognitive Science, 7*(2), 155-170.

Hsu, L., Brewe, E., Foster, T. M., & Harper, K. A. (2004). Resource Letter RPS-1: Research in problem solving. *American Journal of Physics, 72*(9), 1147-1156.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology and Research and Development, 48*(4), 63-85.

Nesbit, J. C., & Adescope, O. O. (2006). Learning with concept and knowledge maps: a meta-analysis. *Review of Educational Research, 76*(3), 413-448.

Nokes, T. J., & Ross, B. H. (2007). *Facilitating conceptual learning through analogy and explanation.* Paper presented at the 2007 Physics Education Research Conference, Greensboro, NC.

Novak, J. D., Gowin, B. D., & Johansen, G. T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. *Science Education*, *67*(5), 625-645.