Implications of Distributed Cognition for PER

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Cognitive Science has influenced physics education research. However, perhaps the community has more to learn from cognitive science. This article will introduce the "radical" notion of distributed cognition, which posits that our surroundings and tools have intelligence. After the introduction of this notion, the article will then discuss a few implications for physics education research.

Introduction

In his seminal article, Edward F. Redish [1] persuasively urged the physics community (and physics education researchers) to heed the lessons of cognitive studies. There are in fact numerous lessons to be learned from cognitive studies and as Redish admits, he was only giving a "narrow slice" of the field. This paper will briefly introduce the ideas behind another slice called distributed cognition. This discussion is intended only as an introduction for a reader who is already familiar with the ideas discussed by Redish. The paper will finish by considering some implications that distributed cognition might have on the field of physics education research.

Distributed Cognition

Distributed cognition is a complex idea, but its defining characteristic is that our surroundings, tools, and culture have embodied intelligence. The recognition of the setting in cognition aligns distributed cognition in the situated learning camp of cognitive science [2]. An example is a good way to begin the discussion of distributed cognition.

Lave [3] studied the math skills of grocery shoppers and dieters and discovered that the math executed by these individuals in natural settings was remarkably accurate (around 95% accuracy). However, when these subjects did the same math in a school setting, their accuracy dropped noticeably (to about 70%). A part of the dieters' success lay in how they used the tools around them. For example, when asked to get three-quarters of two-thirds cups of cottage cheese, the dieters measured out 2/3 of a cup, put it on the counter and then physically created four equal portions, keeping three of them. This type of successful reasoning was used far more frequently (and accurately) than school math, which to an expert is easier (2/3*3/4 = 1/2). Clearly, the surroundings play an important role for the dieters. However, there may be more to their success than just familiarity with the task and having cottage cheese. Perhaps there is intelligence shared between dieter and the measuring cup. It is not important to know what 2/3 means, because the measuring cup *already knows*. This is part of the idea behind distributed cognition.

Distributed Cognition and PER

Distributed cognition is not new to the PER community. Valerie Otero [4] demonstrated the utility of this idea when she studied how a group of students interacted with each other and the tools around them (specifically the CPU computer-based suite of simulations and tools). Clearly, the students in Otero's study have intelligence. It is also reasonable to suppose that the designers of the computer tools have placed something akin to intelligence into the software. However, the real power of Otero's results was that there was intelligence *between* all of these objects, and the effectiveness of this intelligence depends on the abilities of each member of the "cognitive system." Here the intelligence of the system is distributed among all of the members, both computer and human.

Cultural implications

Not coincidentally, the work of Vygotsky (the earliest situated cognitive scientist) with the other Russian cultural-historical psychologists laid the foundations of distributed cognition [5]. They recognized that all cultural artifacts regulate interactions with one's environment and oneself. Furthermore, one's cultural environment contains the accumulated knowledge of prior generations. In effect, culture is the historical legacy of thought [6]. All of the tools, languages and techniques of a culture, such as physics, are the legacy of prior thinking. Distributed cognition is more than intelligence embodied in tools (like a measuring cup) or shared between people, the culture of the individual influences, even defines, the intelligence of the system.

Intelligence

Intelligence manifests itself in how artifacts are used. Intelligence is not a passive quantity residing in our minds. Our intelligence is distributed among the artifacts in our environment. This may seem a little hard to swallow. After all, conventional wisdom suggests that intelligence is in our heads and we all have IQs. This raises an issue: what do we mean by intelligence? One answer might be found in Blooms' Taxonomy of Educational Objectives [7]. Bloom's rankings suggest that there is more to knowledge than just memorization and comprehension. The most challenging aspects of learning: synthesis, analysis and evaluation, are higher-order thinking skills. Such skills include critiquing, creating, designing, and inferring. We can define from Bloom two levels of intelligence, higher-order and rote.

Salomon [8] argues that we cannot expect our environment (leaving out AI computers) to execute higher-order thinking. These skills are the purview of the individual. Certainly, the environment or culture can facilitate or disturb this higher-order thinking, but it is the individual who initiates the cognition. Rote intelligence, like memorizing a grocery list, can easily by distributed.

In a physics classroom, we typically have two global definitions of higher-order physics intelligence: our students will do *and* understand physics. When we think of our students doing physics, we envision action. These actions will typically manifest themselves through interactions with the environment through the use of tools and representations. This is distributed cognition. Understanding in physics means to most physics education researchers, that the students have developed appropriate mental models. While the exact structure of the mental models created by the students is debatable, these models most likely include the representations and tools of physics; another hallmark of distributed cognition.

Sharing and off-loading

The difference between rote and higher-order intelligence provides one distinction for our introduction to distributed cognition. There is another operational distinction. Salomon discusses two approaches in which our intelligence is distributed. One approach is for the individual to *off-load* the cognitive burden onto a tool or onto human partners. A simple example might be the shopping list, which remembers what we need to buy, or the pile of stuff by the door for us to take to the office. Another example would be the group that divides an assignment, goes home individually to work in isolation, and then meets to reassemble an incoherent whole. In each case, there remains a division of labor. The list cannot do the shopping without us. The individual student does only part 2 of the assignment.

The second approach of distributed cognition is *sharing*. Sharing is characterized by a partner who "activates, provides meaning to, and possibly directs the cognitive activity [9]" of another. Cooperative groups which function well are one obvious example of sharing the load, as is a teacher functioning as a facilitator. Otero suggests another: imagine a computer tool that adapts to the characteristics of the interaction. We need to design educational environments that optimize both sharing and off-loading.

Person-solo and Person-plus

A metaphor developed by Perkins [10] provides a nice model (and two very useful terms) for distributed cognition. Consider a student in a history course who has created careful and well-organized notes. Traditional theories about learning only value what is in the student's mind plus the cognitive residues of having created this notebook [11]. This is the *person-solo* model. In contrast, consider the person plus their surrounding (*person-plus* model). Here the student has put a serious cognitive investment into the notebook. It contains summaries, conclusions and it functions as a well-organized memory bank (if not also part of the student's mental model). Together the person plus notebook is a formidable intelligence. For an example closer to home, a physicists plus integration table (or *Mathematica*) is a better [12] physicist than the same person working solo because of the distributed cognitive load.

Summary

This introduction to distributed cognition began with the radical notion that intelligence distributes throughout our surroundings and is not just in our heads. Intelligence is defined by actions and interactions with people, tools, and representations. These actions and interactions have a cultural legacy associated with them because there is intelligence embodied in the tools and representations by their creators. Next, our introduction placed some constraints on this distribution of intelligence. Rote intelligence can distribute into the environment, higher-order cognition cannot. The distribution of intelligence takes two forms, sharing and off-loading. Most educators would prefer the balance between the two forms to favor sharing. In summary, this introduction has distinguished between the person-plus and the person-solo. In both case, cognition is distributed, but with the person-plus we explicitly acknowledge the role of the person's environment. Given this new perspective, what can physics education researchers learn from distributed cognition?

Implications for PER

In this last section, I will go out on a limb and theorize how the framework of distributed cognition might affect physics education research. I will begin by dividing PER into several concentrations such as problem-solving, conceptual understanding, assessment design, gender and minority issues, and attitudes and epistemology. I recognize that the concentrations do not have strict boundaries as our research often overlaps. With these distinctions in place I will now hypothesize how distributed cognition might influence each concentration.

Problem-solving

Of the PER concentrations, problem solving has the most to gain from the distributed cognition perspective. We need to pay special attention to how and when students use (or don't use) tools and representations in their problem solving. Perhaps new tools can be designed given our awareness of distributed intelligence. Computer tools are a powerful way to accomplish this, but they need to be designed with a principled approach and not driven by technological tricks. For our research methods, distributed cognition allows us to draw conclusions from student solutions because we are examining a valuable artifact of the student's cognition. Finally, we can consider research into problem-solving strategies. Pea [13] has noted distributed cognition in problem-solving strategies whereby the paper (or computer program) reduces the cognitive load. Ideally, strategies should share (and not just off-load) the cognitive burden. We need to design evolving problem-solving strategies that go beyond just scaffolding. These new strategies should adapt to both the changing content and dynamics of the person plus environment. When students adopt these strategies, their use should leave a "cognitive residue." Identifying and measuring these residues should be a useful research direction.

Conceptual understanding

For valid reasons, PER is dominated by interviewing techniques to investigate student cognition. However, interviewing techniques seem to assume the person-solo [14]. Should we demand independence from all tools and artifacts or is it better to study how they are used and incorporated? In addition, there is the issue of what concepts and tools we choose to teach. Perhaps it is time to revisit our historical legacy [15].

Assessment Design

Reliability and validity are the two most important aspects of assessment design. Distributive cognition raises issues for each. For example, our tests implicitly assume the person-solo. This affects our validity since the person-plus exists. The questions we ask will share the cognitive load for some students while hindering other students. We need to reconcile this effect since it impacts reliability. In summary, we must design assessments that acknowledge the test is a part of the person plus system.

And the rest

Gender and other underrepresented groups studies and research into student attitudes and epistemologies are related to each other through the impact the tools of physics have on our students. The intelligence embodied by the tools of physics (and the unintended consequences of this historical intelligence) may offer new avenues for research [16]. There may be better classroom expectations, problem clues, representations, and tools that could embody equitable thinking for the next generation of physicists.

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References

[1] E. F. Redish, "The Implications of Cognitive Studies for Teaching Physics," *Am. J. Phys.* **62**(6), 796-803 (1994).

[2] Situated Learning has its detractors. See the excellent debate in Anderson, Reder, and Simon, "Situated Learning and Education," *Educational Researcher*, 5-11 (May, 1996) and Greeno, "On Claims that Answer the Wrong Questions," *Educational Researcher*, 5-17 (January /February 1997).

[3] J. Lave, Cognition in Practice: Mind, mathematics and culture in everyday life. (Cambridge University Press, Cambridge, England, 1988).

[4] V. Otero, "Conceptual Development and Context: How do they relate?' *PERC Proceedings 2001*, 49-52 (2001).

[5] M. Cole and Y. Engeström, "A Cultural-historical Approach to Distributed cognition," in *Distributed Cognitions,* G. Salomon ed., (Cambridge University Press, Cambridge, 1993).

[6] Unfortunately, culture is a legacy of both good and poor thinking. Sometimes there is evidence of no thinking at all.

[7] B. Bloom and D. R. Krathwohl, *Taxonomy of Educational Objectives: The Classification of Educational Goals Handbook I: Cognitive Domain.* (Longmans, New York, 1956). While this might be an outdated and outmode construct to some, it still provides a framework.

[8] G. Salomon, "No Distribution without Individual Cognition," in *Distributed Cognitions,* G. Salomon ed., (Cambridge University Press, Cambridge, 1993).

[9] G. Salomon, p. 133.

[10] D. Perkins, "Person-plus: a distributed view of thinking and learning," in *Distributed Cognitions,* G. Salomon ed., (Cambridge University Press, Cambridge, 1993).

[11] Who among us hasn't been warned of the perils of thinking when stranded on a desert island?

[12] Better implies more efficient. In both cases, the physicist needs the metacognition to evaluate the results given either by the external sources or by hand.

[13] R.D. Pea, "Distributed intelligence and designs for education," in *Distributed Cognitions,* G. Salomon ed., (Cambridge University Press, Cambridge, 1993). I highly recommend reading this book.

[14] Even in the case of clinical interview. The equipment is seen as prompts and not a part of student sense-making. Furthermore, think-aloud protocols rarely notice how a tool is used and how the embodied intelligence of the tool is affecting cognition.

[15] Thomas Moore, Bruce Sherwood and Ruth Chabay are already doing some of this. See their textbooks.

[16] Laura McCullough has assured me that some scholars are researching this issue.