Using The Algebra Project Method To Regiment Discourse In An Energy Course for Teachers

Hunter G. Close*, Lezlie S. DeWater*, Eleanor W. Close*, Rachel E. Scherr*, Sarah B. McKagan†

*Department of Physics, Seattle Pacific University, Seattle, WA 98119
†McKagan Enterprises, Seattle, WA 98144

Abstract. The Algebra Project, led by R. Moses, provides access to understanding of algebra for middle school students and their teachers by guiding them to participate actively and communally in the construction of regimented symbolic systems. We have extended this work by applying it to the professional development of science teachers (K-12) in energy. As we apply the Algebra Project method, the focus of instruction shifts from the learning of specific concepts within the broad theme of energy to the gradual regimentation of the interplay between learners' observation, thinking, graphic representation, and communication. This approach is suitable for teaching energy, which by its transcendence can seem to defy a linear instructional sequence. The learning of specific energy content thus becomes more learner-directed and unpredictable, though at no apparent cost to its extent. Meanwhile, teachers seem empowered by this method to see beginners as legitimate participants in the scientific process.

Keywords: Energy, professional development, graphic representation, discourse.
PACS: 01.70.+w, 01.40.jh, 01.40.Fk, 01.40.E-

INTRODUCTION

As the energy consumption of the human race grows, so does the need for effective instruction in schools that authentically addresses the relevant theoretical and practical issues around energy. When challenged by the needs of our local community to provide professional development courses for in-service teachers on energy, we recognized the pedagogical incompatibility between our own familiar instructional paradigm and the understanding of energy that we hoped for our community of teachers to achieve, both in extent and character. On one hand, our existing instructional expertise prepared us to lead teachers to engage in guided, linear sequences of logic within the borders of carefully pre-chosen, simplified physical scenarios – those in which we the instructors could easily limit the topics of teacher-contributed discourse to conceptual issues for which we had prepared. On the other hand, our goals for teachers included that they would recognize the universal applicability of the theory of energy beyond any short list of scenarios, and beyond these "school-scenarios" in general, to what we might call "real life." (After all, without the broader community's interest in energy in "real life," we would probably not have been supported to provide these professional development courses in the first place.) Furthermore, our epistemological view of the theory of energy, namely, that a fundamentally unproved *belief* in the conservation, transfer, and transformation of energy is necessary for a functional understanding of energy, suggested a limited role for logic in the *induction* of teachers into the (logical) use of the theory.

Our own (attempted) release of control over topical coverage and instructional sequence (on multiple instructional time scales) called for another framework to be introduced into instruction in order to achieve some adequate level of discipline and accountability in classroom discourse. Through the Algebra Project [1] we found an alternative instructional method that seeks less to direct the specific content of the learner's thinking and more to regiment the relationship between that thinking and its expression and communication through multiple representations. The Algebra Project method has thus allowed us to meet our goals of maintaining focus on a broad overview of energy and on (certain species of) scientific reasoning, while capitalizing on existing community interest in energy by providing opportunity (and responsibility) for the teachers to have greater ownership of the ideas.

CP1289, *2010 Physics Education Research Conference*
edited by C. Singh, M. Sabella, and S. Rebello

This paper describes the initial inspiration for the Algebra Project method, the method itself, and how we adapted the method for teachers and energy. Finally, we discuss implications for learner empowerment.

THE ALGEBRA PROJECT

Regimentation of Ordinary Discourse

Moses framed cognitive instructional problems through a notion that we call the "permanent installation of a question" into a child's mind in relation to a particular concept. For example, Moses noticed that a student failed to take algebraic sign into account when performing arithmetical calculations (as in, $8 + (-5) = 13$). To do this calculation correctly, one must be concerned with two questions about number: "How many?" and "which way?" The child who makes the mistake above has the question "how many?" associated with number, but not the question "which way?" Thus, the solution to the instructional problem involves somehow installing that missing question into the child's mind.

The philosopher of mathematics and science W. V. O. Quine [2] provided insight to Moses for a method to accomplish this installation of a question about a concept:

"... A fenced ontology is just not implicit in ordinary language. The idea of a boundary between being and non-being is a philosophical idea, an idea of technical science in a broad sense. Scientists and philosophers seek a comprehensive system of the world, and one that is oriented to reference even more squarely and utterly than ordinary language. Ontological concern is not a correction of a lay thought and practice; it is foreign to the lay culture, though an outgrowth of it. We can draw explicit ontological lines when desired. We can regiment our notation...At other points new ontic commitments may emerge."

Here Quine describes how it is not natural to ordinary speech and thought to have a consistent concern about certain properties of certain objects (in this case, the concern about the direction of a number). The first step in solving the instructional problem is thus to recognize that scientists (including mathematicians) have a special relationship with language that is implicit in scientific culture, and that people uninitiated into that culture will not, in general, be committed to asking the same questions about every concrete instance of a concept. The next step in the solution is in Quine's suggestion that "we can regiment our notation"; through the introduction of a community-generated abstract symbolic system, that community of learners can be initiated into engaging with that system in a regimented way that remains committed to a precise relationship between thought and language, and to a certain set of features about each of the community's abstract concepts.

The Five Steps of the Instructional Method

Moses defined five steps that scaffold the eventual regimentation of discourse by a group of learners around a symbolic system. We describe the steps and offer our own interpretations and reflections from experience.

1. Physical Event

The Physical Event is a field trip or some other raw experience. The teacher does not prepare the students for the experience with any formal abstractions for directing their attention; instead, the intention is for students to attend to whatever they want. When Moses applied this process to the (eventual) teaching of the number line, students rode around on a public transit system for the event. In this case, the instructor (Moses) strategically chose a particular experience because he expected that the abstractions contained by the number line would be well exemplified by the transit system.

2. Pictorial Representation / Modeling

This step of the process builds a bridge between the embodied experience and writing. Students draw pictures of their experience in whatever way they want, drawing attention to whatever features they found personally salient.

3. Intuitive Language / "People Talk"

This step is an extension of the previous one, in that students are representing whatever aspects of the experience were important to them, but this time in writing. For reformed instructors like us who are eager to engage in dialogue with students about concepts, it is important to note that, in this step, it would be inappropriate to respond to student contributions in ways that hold them accountable to our own inner standards of sense-making, conceptual development, logical consistency, precise definitions of terms (though they be student-generated), *etc.* To do so is to subvert the fourth step, in which the community of students negotiates the commitments to which they will be held accountable; that is, before they are negotiated, they are not the students' commitments, but the instructor's.

4. *Structured Language / "Feature Talk"*

In the fourth step, students abstract key features from the plethora of the community's accounts of their concrete experiences. In Moses' number line case, students took a trip on the transit system, so the students were charged with determining a set of abstract features that can be used consistently to describe the event. Regardless of circumstantial details of the trip (*e.g.,* "we saw a duck"), all trips may be described with the set of abstract features: *start, finish, direction,* and *distance.* Students negotiate these common features through discussion with each other and the instructor.

In our experience so far, the instructional challenge of this phase is that *feature* is itself an abstraction (in fact, it is an abstraction of abstractions) that is being used to provide scaffolding for explicit instruction on the process of abstracting from experience. Since the involved logic seems to be turned upside-down, we have sought thus far to teach this process by example, drawing on other, more familiar forms of regimented discourse with commitments to certain features. As examples, airline booking agents and medical assistants have certain sets of questions that they ask in order to describe the relevant abstract features of an airplane trip or medical patient, respectively. The fact that the answers to these questions constitute a necessary and sufficient description of the itinerary or the health of the patient illustrate the regimented quality of discourse that is employed. On the point of the difficulty in instructing students about features, it is worth noting that this method assumes that students attend to certain features starting as early as step 2; however, these features were probably not articulated or shared by the community before step 4. Thus, instruction on features relies on the natural, common cognitive process of attending to features. "Feature talk" is therefore primarily about making this natural process explicit and forming a consensus.

5. *Symbolic Representation*

In the final step, students invent a symbolic language whose primary function is the expression of the featured information (from step 4). The regimentation of discourse by the community is developed through persistent explicit discussion about the strict correspondence between the negotiated features and the symbols representing those features. These symbolic languages are at first private, but over time are understood by more members of the community. It is not necessary for them to converge; instead the priority should be for the system(s) to correspond ever more squarely and consistently to the negotiated features.

APPLICATION OF THE METHOD TO THE LEARNING OF ENERGY

For the physical event (step 1), we have directed teachers to take a brief walk (~20 minutes) along a canal near our building and to look for "energy doing whatever it's doing." Directing their attention to energy may seem like the imposition of an abstract feature onto their experience, and perhaps it is; however, we have felt it necessary to provide some minimal structure in order to ensure some commonality of experience. On this walk, teachers have noticed things like kayakers, power lines, hot cars in the parking lot, leaves blowing in the wind, birds flying, water waves, an air conditioner, *etc.*

Upon return to the classroom, teachers draw and label diagrams of what they saw (step 2). These diagrams, which are done in small groups (3-5) on whiteboards, are almost exclusively snapshot-like pictures of objects with simple labels, supplemented occasionally with ambiguous arrows, perhaps to represent flow of energy, flow of some sort of causal power, or to guide the reader's attention through the picture. As expected, many issues addressed by the diagrams are not handled consistently: arrows within one diagram appear to have varying meaning; the form, location, amount, and evidence for energy are sometimes addressed clearly and sometimes not.

During "people talk" (step 3), the teachers walk around and talk in a sort of "art show opening" format, asking questions of each other according to their own interest.

During "feature talk" (step 4), we invite teachers to reflect, considering the physical scenarios that they have presented, on what short list of questions would, if answered, provide the most important information about what the energy is doing in each (or any conceivable) scenario. The community-generated list is often at first very long and redundant. In this case, we have challenged small groups to choose their "top five" questions; these selections are tallied on the master list, and the result is a short list of features that is satisfying to both the instructors and the teachers. This list generally includes identifying the relevant objects in which the energy is located, specifying beginning and end times for the analysis, describing the amounts of energy involved, identifying the form(s) of energy at different times, and considering the observational evidence for the locations and forms of energy. Other common concerns involve issues related to the history of a specific parcel of energy, such as how it was acquired from the environment for the electrical grid or how "used up" or degraded it is. These concerns are generally not sufficiently popular that they get taken up by the large group; in this case, the instructors ask teachers to remember their concerns and to examine whether these questions get addressed through our analysis using the features that have been adopted by the large group.

We have augmented the symbolic representation step (step 5) through the use of an embodied learning activity developed by the authors called "Energy Theater" [3]. We believe this augmentation is useful to (and perhaps necessary for) teachers and is faithful to the original method. To describe accurately the features of energy that we have negotiated requires the management of a relatively large amount of dynamic information that is coordinated among a multiplicity of energy units in space, time, and form. Energy Theater seems to provide teachers with the ability to process this high volume of information in an embodied representation, in a way that is accessible for later symbolic representation. Thus, Energy Theater provides a bridge between the challenges of addressing the features and representing them diagrammatically. We believe it is faithful to the Algebra Project because it follows the same pattern of providing a physical basis for generating pictorial representations.

The basic formula for teachers' engagement in step 5 is for them to use a series of physical scenarios to refine the correspondence between their representation, the negotiated features, and observable reality. For instance, teachers might agree that the box in a given scenario is moving at constant speed and therefore should be represented as having constant kinetic energy; their challenge is then to find a consistent way to show that the box has constant kinetic energy. The challenges for teachers include some conceptual issues but are dominated by the high cognitive demand of managing many pieces of information and their consistent correspondence to symbolic expression, and of maintaining a commitment to attending to the negotiated features. The primary functions of the instructor in this learning environment are to help teachers maintain their commitments (or reconsider them, if appropriate) to the concrete and abstract represented things and to the representing system, and to help them interpret their representations, as in "This diagram says this to me… is that what you mean?" and "Why did you draw this thing this way?"

The preceding discussion illustrates what was meant in the introduction by "certain species of scientific reasoning": the rigorous correspondence between that which represents and that which is represented, and the deliberate selection of the abstractions that will be represented. These skills can be placed in contrast to what is probably more familiar to reformed science instructors: teaching for understanding the basis for and status of scientific knowledge. These values are often exemplified by A. B. Arons' famous questions "How do we know?" and "Why do we believe?" [4]. To highlight the contrast of these two approaches, we can imagine attributing to Moses the different questions "How do we show?" and "What do we believe is important?" In this way, we can provide learners with access to the decision-making process about what basic material will constitute scientific knowledge and how scientific discourse will stand in relation to ordinary discourse.

LEARNER EMPOWERMENT

Curriculum focused on the construction of representations seems especially suited for learner empowerment, for one multi-faceted reason: learners can make a contribution. The reason is multi-faceted because (a) the level of mastery that is accomplished by the teachers is higher than many of them have ever experienced in science, especially among elementary teachers. We believe the mastery is high because of the access to the world of energy that is afforded by Energy Theater. (b) Representation construction is an essentially creative act that does not require new information so much as a new perspective. In many cases, teacher-generated energy diagrams surpass those of many textbooks in explanatory power. (c) The regimentation process illustrates for teachers how the difference between ordinary experience and scientific experience can be a simple yet profound mix of persistence and creativity.

ACKNOWLEDGMENTS

We are grateful to Chandra Turpen and Noah Finkelstein for providing a forum for the discussion of these ideas in a targeted poster session at PERC 2010. We also thank Valerie Otero for her insight into the role of language development in the learning of science. We thank Lane H. Seeley, Stamatis Vokos, and Renee Michelle Goertzen for their substantive contributions to discussions about this work. This work was supported in part by the National Science Foundation (Grant No. DRL 0822342).

REFERENCES

1. R. P. Moses and C. E. Cobb, Jr., *Radical Equations: Civil Rights from Mississippi to the Algebra Project*, Boston: Beacon Press, 2001, pp. 120-122.
2. W. V. Quine, *Theories and Things,* Cambridge, Mass.: Belknap Press, 1981, pp. 9-10.
3. R. E. Scherr, H. G. Close, S. B. McKagan, and E. W. Close, ""Energy Theater": Using the Body Symbolically to Understand Energy," this volume.
4. A. B. Arons, "Achieving Wider Scientific Literacy," *Daedalus*, Spring, 1983, pp. 91-122.