Energy In Action: The Construction Of Physics Ideas In Multiple Modes

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Abstract. In a course organized around the development of diverse representations, no single mode of expression offers a complete picture of participants' understanding of the nature of energy. Instead, we argue, their understanding is actively constructed through the simultaneous use of a range of quite different kinds of representational resources (Goodwin, 2000; Hutchins, 1995; Ochs, Gonzales, & Jacoby, 1996), including not only words and prosody but also gestures, symbolic objects, participants moving their bodies in concert, and whatever other communicative modes the course invites them to use. Examples are provided from a teacher professional development course on energy.

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INTRODUCTION

In our work in designing professional development courses for teachers, we use as a design principle the idea that promoting multiple methods of communicating meaning allows participants to draw on a variety of cognitive resources to construct understanding. This gives participants, instructors, and researchers access to a richer and more complete picture of the meaning being constructed than any single channel of communication can provide.

MEANING ON MULTIPLE CHANNELS

The claim that meaning is communicated on multiple channels, particularly in situations in which participants are free to move around, is supported by cognitive theory suggesting that communicative interactions and construction of meaning take place through simultaneous use of a wide variety of semiotic resources.

For example, in a brief exchange among girls playing hopscotch [1], when one girl makes a mistake, the second girl communicates the error to her using words, parallel grammatical construction, speech rhythm and intonation, hand gestures, foot stomps, orientation of body and gaze relative to the first girl, and positioning of her body relative to the (interrupted) motion of the first girl. The meaning of the words spoken by the second girl is only one among many channels of communication that together convey much richer meaning than the words alone could do.

This example illustrates the wider rule that the words spoken in any interaction convey only part of the meaning of the interaction. In other documented examples, physicists enact and empathize with physical phenomena using words, gestures, and graphic representations to make sense of experimental results [2]; pilots map abstract concepts onto physical space using symbolic objects to facilitate complex operations [3]; and elementary students use gesture in constructing mathematical explanations, which increases their cognitive capacity for other related tasks [4]. It follows, we believe, that an instructional framework with a narrow focus on verbal or written communication restricts many opportunities for both conveying and constructing meaning.

Many Channels Of Communication Are Restricted In Classrooms

In traditional classroom situations, students are seated, often in individual desks, and often all facing toward the front of the classroom. This physical arrangement of participants leads to the restriction of many forms of expression. The posture and orientation of the body is limited, and therefore meaning is generally not communicated through whole-body physical action. Use of gesture and other symbolic systems is also limited, in part due to the difficulty in

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using these in such a way that the entire audience (including the instructor and other students) can observe the gestures. In this and other ways, traditional classroom discourse privileges the use of words to communicate meaning.

In a tutorial-style instructional setting, groups of students often sit around a table facing each other, usually with a paper document in front of them, and sometimes with laboratory equipment present on the table. Students are typically seated and engaged in either talking or writing. Many channels of communication remain restricted in this setting. Use of physical objects is still limited: more often than not, the only objects available are pencil and paper. More use of gesture is possible, but motion is still limited: students are not often invited to stand up and move around, to act out a physical scenario, or to use their body position or posture to convey meaning.

In both traditional and tutorial settings, restricted semiotic resources for the learner also restricts the possibilities for formative assessment by the instructor, and the access by researchers to observable evidence of cognitive processes.

Targeted Instructional Activities Can Open And Promote Use Of Multiple Channels

We are interested in instructional activities that encourage participants to make use of multiple semiotic resources to communicate meaning. One such activity is Energy Theater, an activity in which participants use their bodies to represent transfers and transformations of energy in physical scenarios. Energy Theater has the following rules: (1) Each participant is a unit of energy that has one and only one form; (2) Objects in the scenario correspond to regions on the floor; (3) As energy moves and changes form in the scenario, participants move to different locations on the floor and indicate a change in form.

Participants work in groups to co-construct an Energy Theater representation of a specific scenario. The form of each unit of energy can be indicated in various ways, including colored cards, pieces of paper with letters or words written on them, and hand signs. Energy Theater is described in more detail in a separate paper in these proceedings [5].

Because it is a physical representation that requires participants to use their bodies to enact their understanding, Energy Theater promotes the use of multiple channels of communication to convey meaning. In the sections below, we will describe a few of these channels in the context of a short episode of Energy Theater from one of our professional development courses for teachers.

INSTRUCTIONAL CONTEXT

The example of Energy Theater described below took place in a summer professional development course for in-service upper-elementary teachers. The course was designed to introduce teachers to various ways of representing and thinking about energy transfers and transformations, and to provide opportunities for teachers to use the representations to develop their own conceptual understanding of energy as well as consider how to enhance energy-related instruction in their own classrooms.

In this course, participants used a stack of colored cards made of construction paper to indicate forms of energy; each color represented a different form. A change from one form of energy to another was represented by flipping the cards to change which card was visible on the front of the stack.

GATHERING INFORMATION ON THINKING ABOUT ENERGY

The descriptions below are drawn from a 90-second episode of Energy Theater that took place as part of naturally occurring classroom events. The close examination (using video) of a short, data-rich episode is a case-study approach that supports our goal of understanding the details of what individuals do to learn in collaborative science learning activities [6]. In this episode, a group of six teachers is working together to represent the energy transfers and transformations in the following scenario: a box begins at rest, is given a push by a hand, slides across the floor, and slows to a stop. This is one of the first few times the participants have used Energy Theater. Prior to this episode, these six teachers had decided that kinetic, chemical, and thermal energy would be indicated by the green, orange, and red construction paper cards, respectively.

At the beginning of this episode, the six teachers are in the process of arranging themselves into a line, standing side by side and all facing the same direction. They are discussing "who will be the hands," and agree that all of them will be the hands. They then discuss how to represent the hands pushing the box; the solution they arrive at is for each of them to make a pushing motion with one hand, in unison, then arrange themselves into a box formation (two rows of three people standing next to each other) and move slowly forward. They spend some time negotiating the best way to transition from the initial six-person line into the box formation, including the issue of what gestures need to be part of their motion and when they should flip their cards to indicate a change from chemical energy (orange) to kinetic energy (green).

Once the teachers have moved a few steps in box formation, they negotiate who will transition from kinetic energy (green) to thermal energy (red), where and how each person will move while making that change, and in what order participants will leave the box formation. In the end, all six teachers have turned to their red cards and have left the box formation.

In the sections below, we describe several different channels (or semiotic resources) used by participants to communicate meaning during the Energy Theater episode described above.

Words And What They Mean

One way in which the teachers communicate meaning is through the words they speak. This is perhaps the most commonly recognized semiotic resource in typical classrooms. While our interest in this paper is to describe other, less often utilized channels of communication, we do not mean to imply that spoken words are unimportant in communicating meaning, both between participants and for instructors and researchers. For example, as the group enacts the transition from the hand-pushing formation to the box formation, one teacher says "As we push, we turn to green..." This statement communicates to her colleagues what action she thinks they should all be completing with their colored cards.

In addition, the statement "As we push, we turn to green..." communicates a somewhat ambiguous status for the participants in the Energy Theater context: first it seems consistent with participants representing the hands pushing the box ("As we push, ..."), but in the second half of the statement ("...we turn to green...") the participants are identified with the color of card on the front of the stack, which is a way of labeling the form of energy. Therefore, the second half of this statement identifies participants as units of energy in the midst of a transformation from chemical form (orange) to kinetic form (green).

Symbolic Objects: Energy Cards

The use of colored cards to represent forms of energy opens another channel of communication [1, 3]. By holding their cards up, turning from one card to another, and looking at each others' cards, participants communicate about what form of energy they are representing or what transformation they think should take place. When the teachers are arranging themselves into the side-by-side line at the start of the video, some are looking at their own cards as they turn to the appropriate color; others are looking at the cards of their neighbors, perhaps to check whether they are in agreement with each other about what form of energy they should be representing at that moment.

The use of colored cards also interacts with the use of words to convey meaning. The teachers do not use the words "kinetic" and "thermal" in this episode; instead, these terms have been replaced with the words "green" and "red," corresponding to the color of the card the group has chosen to represent the respective form of energy. The cards also reinforce and provide a check for the meaning communicated in words. For example, when one teacher says "As we push, we turn to green...," all the other members of the group look at that teacher as she flips the green card to the front of her stack.

Note that the descriptions above are not attempts to assess the usefulness or correctness of the meaning being conveyed using symbolic objects. Rather, we are attempting to establish that when a colored card is shown, information is communicated about what form of energy a teacher thinks should be represented at that moment, and this information is potentially of interest both to participants and to instructors and researchers.

Prosody: Rhythm And Tone Of Speech

The rhythm and tone of speech (prosody) conveys meaning separate from the meaning of the words themselves. Stress placed on particular words can emphasize importance; intonation can indicate whether the speaker is certain, is posing a question to her colleagues, or is suggesting an action [7, 8]. For example, when one teacher says "As we push, we turn to green...," the word "green" is said on a long drawn-out tone and has a complex pitch contour: inflecting upward, then dropping to a lower pitch and from there inflecting upward again to end on approximately the same pitch on which the word began.

The prosody of the word "green" communicates meaning in several ways. First, the length of the word draws attention to it, communicating that it is the focus of the sentence. This length also allows time for the physical process of flipping a colored card to or from the front of the stack, allowing the teacher to enact her statement as she speaks it. The inflection of the word is an example of what is sometimes referred to as "teacher voice," a pitch contour that suggests the statement being made is instructive: not only does the teacher flip her own colored card, but her intonation communicates that she is inviting her colleagues to flip their cards at the same time.

Note that this example of prosody conveys meaning about a necessarily embodied activity: the speaker is enacting something, and invites her listeners to mirror her physical action. We wonder if Energy Theater, which intentionally promotes movement of

the whole body and use of physical signs, may also indirectly promote more varied prosody from the participants. This could be because people have more varied speech inflection when they are directing each others' action; perhaps stimulating dynamic action also indirectly stimulates participants to speak more dynamically.

Body Movements And Orientations

The way participants move while enacting Energy Theater, and the orientation of their bodies relative to each other and the room, convey meaning in this episode both about whose judgment is most valued and about what aspects of the enactment require use of judgment.

In the interaction in which one teacher says "As we push, we turn to green...," the teacher speaking uses her body orientation to preferentially engage the attention of one of the other teachers. As she speaks, she leans forward and turns her head to the side, placing her head in the line of sight of the teacher whose attention she is engaging, and making it possible for her to make eye contact with this second teacher. All five co-participants are looking at the speaker; the speaker, however, continues to move her head and upper body in order to maintain eye contact with one particular participant. This indicates whose judgment the speaker considers most valuable or relevant; indeed, the participant to whom the speaker is directing her attention plays a leadership role in directing her co-participants for the majority of this Energy Theater episode.

During the entirety of the episode, the participants alternate between facing all in the same direction – possibly indicating the idea of a performance – and turning their heads or their entire bodies toward each other – possibly communicating an understanding that something about the Energy Theater representation needs to be worked out. For example, when the teachers initially negotiate their relative positions for the beginning of their enactment of the scenario, they line up next to each other (shoulder to shoulder) but continue to look toward each other, turning or leaning their torsos and turning their heads in order to make eye contact with other participants.

Once they have completed their negotiation, however, the teachers re-form the shoulder-to-shoulder line and stand erect, with a few participants turning their heads only slightly, perhaps in order to coordinate their next movement with the group. The inward-facing orientation, during which teachers' heads and bodies are oriented toward each other, communicates that an aspect of Energy Theater is problematic and needs to be negotiated – understanding is being constructed. The forward-facing orientation, during which teachers are all facing the same direction and are not making eye contact with each other, communicates that consensus has been reached and the group is rehearsing the actions they have agreed upon. This communicates not only what the group has and has not negotiated, but also what actions within Energy Theater the group considers deserving of attention (e.g., the timing of changing from one color card to another) and what actions are thought to be irrelevant (e.g., the timing of individual steps as the teachers move into box formation).

CONCLUSION

Energy Theater is an example of an instructional activity that promotes learner communication using multiple semiotic resources. The examples above show that in Energy Theater, participants convey meaning simultaneously on many different channels. These channels, among others not described here, are not merely background features, but are relevant for assessing the learning taking place, and are therefore of interest not only to participants but also to teachers and researchers.

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