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Teaching Routines to Enhance Collaboration Using Classroom Network Technology

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ABSTRACT

This chapter presents an argument for the use of *teaching routines* (pedagogical patterns) to engage students in collaborative learning activities using the Group Scribbles classroom network technology. Teaching routines are a resource for structuring student opportunities to learn within lessons. They address known challenges associated with making the most of classroom network technology by scaffolding teacher enactment, enabling contingent teaching, and providing an anchor for expanding practice. In this chapter, we articulate the theoretical and empirical basis for using teaching routines to support diagnostic interactive formative assessment of student learning. We describe the goals and features of routines, types of collaboration instantiated in the routines, technological aspects of Group Scribbles, teachers' perceived utility of the routines, and anticipated implementation challenges of the routines within lessons designed for middle school Earth science.

INTRODUCTION

Classroom network technologies enable unique forms of participation in classrooms in which elements of online learning are integrated fully into face-to-face instruction. This class of technologies includes student response systems ("clickers"), networked graphing calculators, and tools that enable participatory simulations. With these technologies, students can work online in private and group spaces while simultaneously participating in classroom activities. These technologies have been the focus of much research in recent years (see, Penuel, Roschelle, & Abrahamson, 2005, for a review), though explicit attention to how teachers can use them well has not been widely studied.

To make the most of classroom network technologies, teachers need support for the design and enactment of classroom teaching strategies to use in conjunction with them. Our candidate for the form that support should take is what we call a teaching routine. Teaching routines are *recurring patterned sequences of interaction that teachers and students jointly enact to organize* *opportunities for student learning in classrooms.* Routines are familiar features of classrooms, and remarkably stable and recognizable across large timescales and distances; they form part of the very "grammar of schooling" (Tyack & Cuban, 1995). Many routines are enacted principally through classroom discourse, as when teachers pose students a question whose answer is known to the students, students respond, and the teacher evaluates the response (Mehan, 1979). Classroom formats for organizing student participation in class, such as recitation, small group discussion, and whole-class discussion are ubiquitous and differ little in structure from subject to subject (Nystrand, Wu, & Gamoran, 2003).

This chapter provides an overview of the challenges to using classroom network technology that routines are intended to address, presents examples of routines developed for a new classroom network technology called *Group Scribbles*, shows how routines have been embedded in lessons designed for middle school Earth teachers, and describes professional development for teachers in using routines. The chapter also presents evidence about how teachers perceive the potential of routines and challenges they anticipate in using them.

BACKGROUND

Technology can transform how teachers organize learning opportunities for students in the classroom. Technology readily facilitates re-use of learning processes (Koper, 2003; Schroeder & Spannagel, 2005; Zumbach, Muhlenbrock, Jansen, Reimann, & Hoppe, 2002), by providing a record of interaction that can be used as a guide for enacting processes again so that they can become routine sequences of interaction. In addition, with the aid of certain forms of classroom network technology, learners can participate anonymously, in ways that may facilitate their willingness to ask for help when they do not understand something (Davis, 2003). With this technology, students can engage in participatory simulations and acts of collective representation that help them master difficult subject matter, from complex adaptive systems in biology to functions in algebra (Hegedus & Kaput, 2004; Stroup, Ares, & Hurford, 2005; Wilensky & Stroup, 2000).

Collaborative Scripts and Design Patterns

The introduction of technology either to change the medium of learning (e.g., from face-to-face to online learning) or to augment face-to-face interaction may necessitate the development of new teaching routines and transformation of existing routines to make the most of new affordances of technology (Penuel, 2008; Roschelle, Knudsen, & Hegedus, in press). Designers of educational technologies have been aware of the need, potential, and limitations of designing sequences of interactions to better facilitate learning for some time. For example, recognizing that on their own, students may not collaborate effectively to learn together, designers have developed collaborative scripts that prescribe how students should form groups, interact, and approach problem solving (e.g., Hoppe & Ploetzner, 1999). Such scripts may facilitate collaboration, but they also have the potential to overly constrain learners' efforts to collaborate to learn in certain situations (Dillenbourg, 2002).

In an effort to help designers of collaborative, classroom network technologies ensure that technology supports a wide, rather than limited, number of ways learners can collaborate, other teams have sought to articulate sets of collaborative design patterns. The notion of a design pattern comes from the field of architecture, where the term refers to common features of well-designed spaces (Alexander, Ishikawa, & Silverstein, 1977). DiGiano and colleagues (2003) developed a set of collaborative design patterns to guide the design of software for emerging classroom network technology, such as networked graphing calculators. Their design patterns articulate different sequences of collaborative activity that could be used to organize learning opportunities across different subject areas. Their intent was to enable designers to think broadly about collaboration, not on the one hand to build in features that "over script" while at the same time supporting the kind of structuring of interaction that research suggests is optimal for individual and group learning.

A limitation of these earlier approaches is that they provide little guidance to *teachers* for how they are to make the most of classroom network technologies. The need for such guidance arises from reviews of research that suggest that unless teachers are able to use the technology to promote discussion and reflection on student thinking, the technology alone is unlikely to improve teaching and learning (Judson & Sawada, 2002). In fact, many teachers do not use classroom network technologies in ways that promote discussion and reflection; not surprisingly, these teachers choose to use technologies less often than those who employ the technology in more powerful ways (Penuel, Boscardin, Masyn, & Crawford, 2007). Below, we review specific challenges teachers face in using these technologies, for which we have designed teaching routines as a tool to address.

Specific Challenges to Teaching with Classroom Network Technologies

One way that the potential of classroom network technologies becomes limited is in how they are used to engage students in thinking about content. One of the most common routines, the I-R-E (initiation-response-evaluation) sequence in which teachers pose a question to students, students answer, and the teacher evaluates the response, offers little room for dialogue among students (Mehan, 1979; Wells, 1993). In science classrooms, the use of this sequence also limits opportunities for students to articulate complex concepts and arguments that are the hallmark of scientific reasoning (Lemke, 1990). Studies of K-12 teachers' use of classroom network technologies indicate many teachers use I-R-E sequences with the technology, without much classroom discussion (e.g., Penuel, Boscardin, et al., 2007). These teachers see less benefit from using the technology, and our conjecture is that they see less benefit because using classroom network technologies in this way does not take sufficient advantage of the shared display as a focal point for attention, discussion, and reflection.

Another challenge is to motivate students to participate in and learn from activities. Particularly in scientific investigations, it can be difficult to help students connect what they are doing to the scientific question (Petrosino, 1998). Students' conceptual development may depend on teachers' providing explanations of phenomena and on learning from text (Klahr & Nigam, 2004), but students may not be motivated to learn from these sources. Classroom network technologies have the potential to help teachers track student progress and also keep students motivated and on task by responding to check-in or reflection questions, but teachers may not be aware of how to incorporate these kinds of procedures with the technologies.

One of the greatest challenges of teaching may be the need for teachers to make multiple decisions about what to do next during a single lesson based on their diagnoses of individuals' and classes' changing understanding of content (Hinds, 2002; Solomon & Morocco, 1999). On the fly, teachers must decide whether to provide feedback to all students or particular students. If feedback is appropriate, teachers need to determine when it should be provided and what form it should take (e.g., written, verbal). Not only are aggregating and interpreting data challenging for teachers who typically have limited training in analysis of assessment data and face multiple demands on their time, but support materials packaged with classroom network technologies and curricula rarely provide this type of "what if" guidance about what to do when students are having difficulty mastering a concept.

TEACHING ROUTINES AS A TOOL FOR HELPING TEACHERS MAKE THE MOST OF CLASSROOM NETWORK TECHNOLOGIES

Teachers need tools beyond curriculum and infrastructure to overcome these known challenges. Teaching routines are designed to help teachers make the most of classroom network technology to improve student learning in the classroom. Depending on their role in the classroom, the grain-size of a teaching routine may vary from a small part of an instructional session (e.g., checking in about progress on a task) to spanning several days or weeks (e.g., an inquiry cycle beginning with identifying research questions, then testing hypotheses in investigations, analyzing results, drawing conclusions, and reflecting on what was learned).

Enhance Classroom Communication

A primary goal for teaching routines is to enhance student opportunities to communicate with the teacher and with peers about their thinking. Classroom network technology makes it possible for teachers to pose questions to *all* students and thus to learn about the class's state of knowledge. In addition, response system technology allows the cycle of question-and-answer to take place in a very short time, thereby providing students and teachers with rapid feedback without slowing the pace of teaching (Roschelle, Penuel, & Abrahamson, 2004). To make the most of network technologies, routines facilitate the design of classroom activities to create multiple opportunities for students to participate, both by contributing responses to student questions and by discussing their thinking with peers and the class. Routines enhance classroom communication by providing guidance about how to facilitate classroom conversations, structuring interactions among peers and small groups, and focusing discussions on epistemological ways of thinking within a domain.

Drawing upon the underlying components of the Peer Instruction model for guiding teaching with student response systems, as well as those of a similar method developed by the Physics Education Research Group at the University of Massachusetts (Dufresne & Gerace, 2004), routines provide useful scaffolds for teachers in orchestrating discussions. Researchers have observed that discussion based on the distribution of student responses encourages student thinking about alternative ways of addressing a concept or problem (Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996) and aids in developing deeper student understanding of the meaning of concepts (Judson & Sawada, 2002). Explanation to a peer has the potential to transform students' misconceptions (Judson & Sawada, 2002). Response systems facilitate discussion by providing an anchor (aggregate responses on a shared display) and a set of artifacts to which students can refer in the process of building knowledge (Truong, Griswold, Ratto, & Star, 2002).

Routines encourage *dialogic,* as opposed to *monologic,* forms of communication (Bakhtin, 1981; Holquist, 1990). Dialogic communication occurs whenever teachers' and students' utterances anticipate and respond to one another, and where the course of a conversation cannot easily be predicted ahead of time. By contrast, monologic communication "speaks with one voice," often the teacher's, and the speaker is not necessarily concerned with learning about the audience's interests, concerns, or questions but rather with compelling them to be, do, or act in a particular way. When students have more opportunity to engage in genuine classroom dialogue rather than recitation, they learn more (Nystrand & Gamoran, 1991). Analyses of learning in science classrooms also highlight the potential of classroom conversations in which students shape the flow and direction of discussion. For example, van Zee and Minstrell (1997) demonstrate a model for orchestrating discussion in which the main goal is to elicit what students think, rather than to evaluate them, and in which subgoals of conversations emerge through particular conversational moves and are not dictated ahead of time by the teacher. These kinds of discussions facilitate students' development of scientific explanations, as well as reflection and revision of ideas about subject matter (diSessa & Minstrell, 1998). Teaching routines may be useful in improving dialogic communication in the classroom, since at present, teachers do not use them widely and many find them more difficult to orchestrate than monologic forms of classroom communication.

While routines are not content- or domain-specific they are structured around important epistemological ways of thinking in a domain. In the case of science, these ways of thinking include designing questions, relating processes, and data creation. Because routines are designed to be applied in multiple instances within a curriculum, specific questions are not identified within a routine, but the steps of a routine are intended to inspire the design of diagnostic questions that will allow teachers to elicit deeper student reasoning.

Diagnostic questioning is consistent with a growing body of cognitive science research that suggests it is necessary to engage rather than ignore problematic student ideas in order to promote conceptual change in science (diSessa & Minstrell, 1998; National Research Council, 1999; Posner, Strike, Hewson, & Gerzog, 1982; Smith, diSessa, & Roschelle, 1993-1994). The diagnostic approach, in its emphasis on eliciting student thinking, stands in contrast with the typical approach of science curricula and with the view of some advocates (e.g., Muthukrishna, Carnine, Grossen, & Miller, 1999) that focus solely on teaching correct concepts to students. To stimulate discussion, researchers have suggested that questions that yield divergent student responses are more effective than those that are easy or lead all students to a single answer (Beatty, Gerace, Leonard, & Dufresne, 2006). The timing of questions further shapes the nature of information an instructor gains about student understanding. Questions posed after a lecture or explanation can be used to check understanding (Dufresne, et al., 1996). Together, these findings suggest it matters not just *what* questions to ask but also *when* to ask them. Teaching routines explicitly address the kinds of questions that are appropriate for diagnosing student understanding as well as when they should be posed to students. As a result, teachers who use routines should be better equipped to address problematic student ideas within and across lessons.

Motivate Students to Participate Productively

A critical role for routines is to create an appetite for learning concepts by tackling a challenge, reflecting on it, and realizing that additional learning is needed (Daniel L. Schwartz & Bransford, 1998). To accomplish this task, routines need to help foster a classroom environment that supports students' developing goals for learning. The emphasis on grades and high-stakes performances that is typical in classroom and standardized assessments creates the opposite kind of environment, namely one in which students orient toward displaying competence and avoiding situations that would show them to be confused or lacking in skill (Maehr & Midgley, 1991; Wigfield, Eccles, & Rodriguez, 1998). By contrast, when teachers provide feedback that is task-focused and that gives specific guidance about how students can improve, assessment can actually help motivate students to learn and create a classroom environment that encourages students to adopt goals for content and skill mastery (Black & Harrison, 2001; Butler, 1987; Butler & Nisan, 1986).

An example of a routine that has as its primary goal motivating learning through feedback is a writing conference (Harris, 1986), in which a student presents a sample of original writing to a teacher or peer, gets feedback, and then revises their paper. The conference begins with an initial effort by the student—planning and producing a draft of his or her own creative or expository writing. Typically, it is the student who selects the topic and organizes the text; students rarely have more than a broad assignment from the teacher to constrain their creativity or imagination. The conference with the teacher or peer is an event where students get feedback, not to make a final judgment on their performance, but to motivate them to make changes to the text to make it clearer, more compelling, more engaging. Students are likely to be motivated to revise their writing on the basis of the conference, to the extent that they are motivated by a desire to write for an external audience, a desire that can be enhanced by the very act of the writing conference.

Improve Teachers' Ability to Use Feedback to Engage in Contingent Teaching

Classroom network technology can play an integral role in improving feedback, by making it easy for teachers to involve all students in assessment and making visible the range of student ideas at any point in a student's learning trajectory (Roschelle, et al., 2004). Classroom network technologies are systems of technology in which individual devices for students and teachers are connected to a local, or classroom-based network; a mechanism to display contributions of students to the system is usually part of the technology (Penuel, in press). Research on this technology suggests its potential for dramatically increasing participation of students, facilitated by the ability to pose questions to all students simultaneously, aggregate results, and present them for all to see and discuss (Penuel, et al., 2005).

Routines of various kinds facilitate teachers' becoming efficient in making instructional decisions on the fly (Calderhead, 1981). Routines can recommend alternative sequences of activities for teachers to follow, depending on how their students are learning from particular curriculum activities. If, furthermore, as a consequence of following a routine in which students have been given the opportunity to learn and are still having difficulty with a concept or skill, routines provide a basis for revising plans for future lessons. Routines can provide such information when they elicit the range of student ideas about a concept (van Zee & Minstrell, 1997), enable active student participation in assessment activities (Black & Wiliam, 1998; Dufresne, et al., 1996), and foster divergent thinking about particular problems (Beatty, et al., 2006; Stroup, et al., 2005).

TEACHING ROUTINES FOR GROUP SCRIBBLES

A central focus of our work has entailed developing routines that leverage Group Scribbles to support teaching and learning of important science content and practices. Group Scribbles (groupscribbles.sri.com) is a general-use collaborative application developed by SRI International. It offers instructors and students a powerful metaphor for thinking about and realizing collaborative learning activities. The metaphor is based on common physical artifacts from the classroom: adhesive notes, bulletin boards, whiteboards, stickers, pens and markers. Participants can scribble contributions on sheets similar to adhesive notes and jointly manage the movement of these electronic notes within and between public and private paces. Because Group Scribbles encourages decentralized control and individual initiative within a collective framework, students are highly involved in both contributing and responding to content.

Group Scribbles allows for open-ended questions that require students to construct an answer *interactively* using a range of representations, including text, sketches, and images. Group Scribbles displays can be continuously manipulated as the discussion proceeds to support emergent collaborative activity. In addition, Group Scribbles supports simple creation of individual and group workspaces to support flexible classroom configurations and highly parallel interactions. Figure 1 displays an image of a Group Scribbles board with student responses.

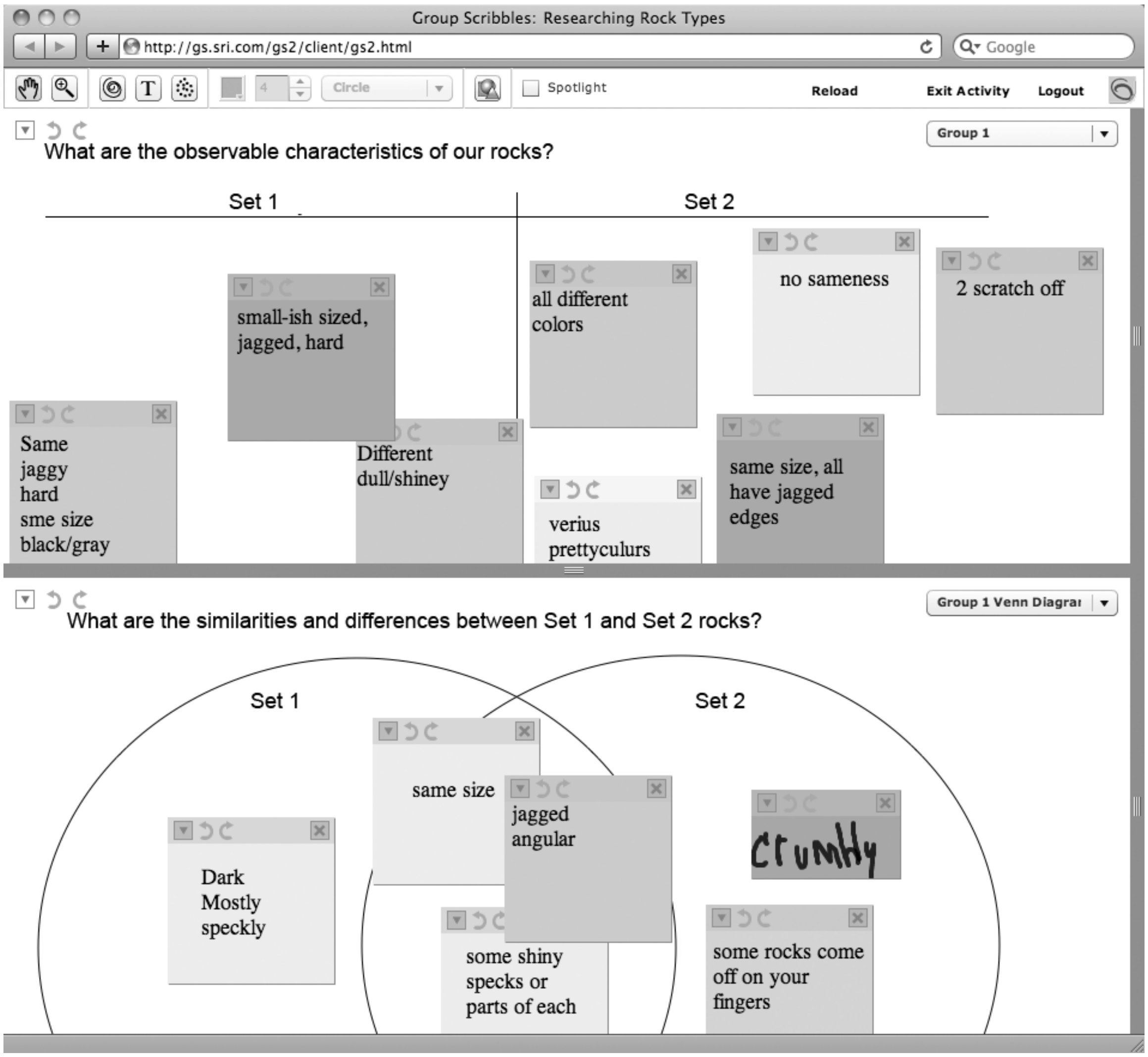

Figure 1. Screenshot of Group Scribbles Boards

A classroom activity can take place entirely within the Group Scribbles environment and the software allows *in situ* assessments of student thinking. This potentially affords the teacher much richer and finer-grained diagnosis of student understanding that is situated within the particular learning occasion. The open-ended structure provides the opportunity for a more contextualized understanding of potentially problematic student ideas and allows teachers to take new and more innovative instruction paths based on their professional interpretation. Teachers using Group Scribbles are able to assess and respond to actual student images and language in an improvisational fashion. They can use multiple attributes of student work as basis for further discussion—either to illustrate a specific misunderstanding or to reframe and re-present knowledge. With this increased flexibility in types of student responses that may be collected, there is the additional challenge of unpacking how students' responses reflect their underlying conceptualizations of the content.

Although Group Scribbles does not require teaching routines, the flexibility of this software provides an excellent occasion for their use. The teaching routines that we have developed help to scaffold for teachers sequences of instructional moves that promote discussion and reflection on student thinking and take advantage of the affordances of Group Scribbles. An outcome of our design process was a collection of seven teaching routines that provide a frame for teachers to enact different sequences of movement across public and private workspaces and between computer-mediated and face-to-face communication to make student thinking transparent. Each teaching routine describes a sequence of instructional moves for creating a particular kind of interactive formative assessment opportunity.

Our seven teaching routines support seven types of interactive formative assessments with Group Scribbles: concept mapping, data creating and sharing, question posing and categorizing, interpreting images, designing tests, and predicting. Each teaching routine follows a design principle aligned to how people learn (National Research Council, 1999). Table 1 outlines the seven teaching routines used in Group Scribbles along with their respective design principles and a brief description of how each routine enhances classroom communication, motivates student participation, and supports contingent teaching practices by improving teachers' ability to adjust instruction. Many of these routines include individual, small group, and whole class work or discussion; all require some student construction of knowledge. To facilitate formative interactions among the teacher and students, a teaching routine can encompass part of an instructional session or an entire instructional session. Some of the routines are particularly well suited for formatively assessing students' inquiry skills (e.g., *Group Data Creation and Comparison*).

Table 1. Teaching Routines for Group Scribbles (GS)

Routine	Design Principle	Instantiation	Goals
Concept Mapping	Construction of causal or other links among concepts helps students grasp important relationships among ideas and enrich their knowledge networks.	Students create concept maps in GS and iteratively revise and refine them with their peers.	*Communication*: Students discuss, debate, and refine their thinking with peers and teacher about how ideas relate to one another. *Participation*: Comparing and contrasting ideas encourages students to reflect upon, clarify and refine their own ideas. *Contingent Teaching*: The teacher gains insight into students' thinking and how students connect ideas.
Design a Test	Designing a scientific experiment, test, model, or procedure helps students learn how to investigate hypotheses.	Students develop an experimental design including independent and dependent variables on a GS board. They invite peer comment, review, and feedback on their designs prior to conducting their experiments/tests.	*Communication*: Students critique and provide feedback on each other's test design. *Participation*: Students use their refined procedures to test their ideas. *Contingent Teaching*: The teacher has an opportunity to assess students' understanding of test design and implementation.
Group Data Creation and Comparison	Organizing and comparing data helps students understand key data to be collected and appropriate representational forms that can be used to display data.	Students work in small groups to organize and represent data using GS. They discuss similarities and differences among the groups' data.	*Communication*: Students present data for peer review and discuss different ways to organize and represent data. *Participation*: Students' own contributions, including data, are a centerpiece of classroom work. *Contingent Teaching*: The teacher obtains feedback on students' abilities in organizing, representing and interpreting data.
Model-based Reasoning: Constructing a Model	Constructing models helps students understand causal relations.	Students construct models (e.g., images, maps, drawings, and pictures) in GS to describe phenomena and their underlying processes. They note the occurrence of processes or events and discuss why these processes/events occur in similar or different locations on the model.	*Communication*: Students share and discuss their models. *Participation*: Students create their own models to represent processes. *Contingent Teaching*: The teacher has an opportunity to assess students' understanding of how two or more processes are related.

Table 1. Teaching Routines for Group Scribbles (GS) (continued)

Routine	Design Principle	Instantiation	Goals
Model-based Reasoning: Interpreting and Using a Model	Interpreting and using models helps students understand causal relations.	Students interpret or explain a visual model posted in GS to explore phenomena and their underlying processes. They note the occurrence of processes or events and make predictions about these processes/events using the model.	*Communication*: Students discuss components of models and how models represent phenomena. *Participation*: Students explore and compare features of models. *Contingent Teaching*: The teacher has an opportunity to assess students' understanding of how two or more processes are related.
Predict with Reasons	Making a prediction (stated outcome) supported with reasons based on conjecture or partial evidence helps students develop reasoning skills and understand the underlying scientific significance of an investigation.	Students describe a likely outcome/prediction for a test, observation, or model using GS. They discuss underlying reasoning for the prediction, and revisit the prediction after an experiment, test, or event is completed.	*Communication*: Students discuss, compare, and refine their thinking about likely outcomes of an experiment, test, or event. *Participation*: Students have a personal investment in conducting an experiment, test, or event. *Contingent Teaching*: Pressing students to base predictions on reasoning provides insight into how well students grasp the significance of investigations.
Question Posing and Categorizing	Developing and refining questions helps students identify questions that can be tested in investigations.	Students use GS to collaboratively generate and share research questions. They discuss similarities and difference among their questions.	*Communication*: Students collaborate with each other to generate and refine research questions. *Participation*: Students are invited to generate questions that will guide their own research. *Contingent Teaching*: Student-generated questions provide feedback to the teacher on students' grasp of the type of questions that are researchable.

Each teaching routine was designed to serve as a template from which an instructional designer, such as a teacher or curriculum developer, can create more specified interactive assessment opportunities. For example, the teaching routine *Group Data Creation and Comparison* (shown in Figure 2) identifies the key steps for enacting the routine to support students in collaborative collecting, organizing, sharing, and comparing of data. Because the teaching routine is generic in design and not linked to specific science content or lessons, it can be used as a foundation for creating assessment opportunities with Group Scribbles within or across lessons and units of instruction encompassing the same or different content. In this way, teaching routines encourage a level of consistency in assessment practice that enables both teachers and students to gain familiarity and comfort with enacting formative assessment over time.

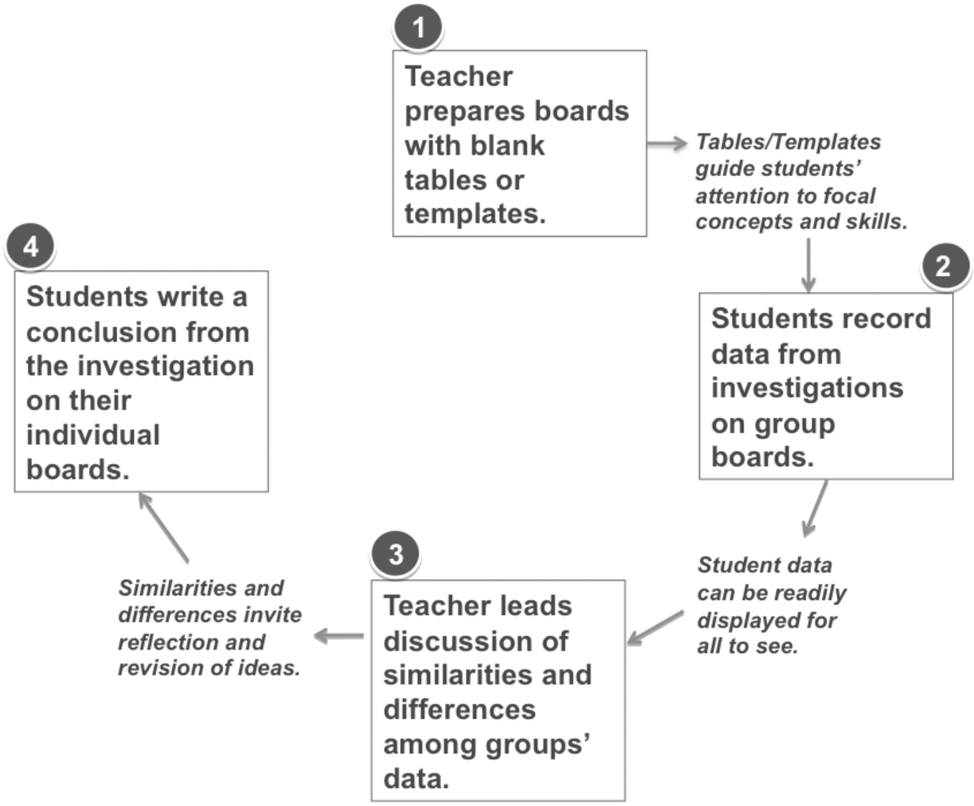

Figure 2. Group Data Creation and Comparison *Routine*

Interactive Formative Assessments Based on Teaching Routines

The final step in our process was to use the teaching routines to develop content-specific *interactive formative assessments (IFAs)* within lessons of a middle school Earth Systems science curriculum.. An IFA is a technology-supported formative assessment designed to promote student learning through the teacher's use of diagnostic questioning and contingent teaching techniques. An IFA is a unique form of formative assessment because classroom network technology, in this case Group Scribbles, supports even greater collaboration and interaction among the teachers and students than are typically possible in classrooms. The adaptive assessment and instructional sequences in IFAs support the practices of eliciting student ideas and using feedback in formative ways to inform decisions about what to do next during instruction. All IFAs developed for this project adhere to four key principles, elaborated below.

IFAs build from existing curriculum materials. We have chosen to build assessments using a particular middle-school Earth science curriculum, *Investigating Earth Systems*, for a number of reasons. First, these materials are already widely adopted, and focused additions to the curriculum have a good chance at being incorporated into future editions of the curriculum. If that happens, the scalability of our materials is greatly enhanced. Second, these materials have been evaluated in an efficacy trial; when coupled with professional development that prepares teachers to adapt these materials to their local standards, the curriculum can be effective in increasing student learning in Earth science (Gallagher & Penuel, 2009). Third, the curriculum provides a useful anchor point for constraining development of both activities and assessments. Our aim is not to develop summative assessments but rather assessments that can be used to adjust instruction. Embedding them into materials teachers use to plan instruction provides the kind of guidance teachers can use to make the most of assessment information.

IFAs incorporate routines. When assessments incorporate routines, they can serve as models for teacher adaptation and lesson creation. Incorporating the routines into assessments will make visible the versatility of routines as resources for development and will also provide concrete illustrations that reflect our best thinking about how assessments can be designed with the technologies.

IFAs incorporate learning processes consistent with research on how students learn from participating in assessment activities in science. Key processes for learning from assessment in science activities are feedback and student reflection. Feedback helps students understand what they know and also to know how to improve (Black & Harrison, 2001; National Research Council, 2001). Network technology provides another source of feedback that may be important to learning: feedback on what others know and are having difficulty learning (Penuel, et al., 2005). Good classroom assessments also have students reflect on and revise their ideas (Black & Wiliam, 1998; National Research Council, 1999, 2001). Network technology supports reflection indirectly, by providing a focus (a shared display) for reflection, but to be effective, teachers must facilitate discussion of ideas to make reflection an integral part of a networked classrooms. The assessments will provide examples of how to foster reflection by providing more concrete guidance than do the teaching routines about questions to pose and about how to orchestrate classroom discussions.

IFAs integrate diverse sources of expertise. Developing assessments that incorporate network technology, employ routines, and assess Earth science content and skills requires a diverse set of expertise. Software engineers are needed to clarify the current and possible capabilities of the technology and to support classroom implementation. Learning scientists are needed to develop lesson plans using routines that reflect what we know about how people learn. Assessment and subject matter experts are needed to develop diagnostic questions and see to it that the connections encouraged in the IFAs reflect both accurate and significant content. Teachers' perspectives are needed to address questions about what is feasible to implement in real classrooms with students at particular grade levels.

In our work, each IFA has the same components as a teaching routine but is tailored to a lesson and its learning goals. Because IFAs are embedded within lessons and directly align with the target content of lessons, they can only be used with Group Scribbles in specified lesson contexts. For example, the *Model-based Reasoning: Constructing a Model* routine (Figure 3) was used to design an IFA within an Earth Systems lesson on tectonic plate boundaries (Table 2). In this way, a teaching routine becomes a resource for designing IFAs within lessons. As illustrated in Table 2, each step in the routine becomes instantiated within the *Ring of Fire* IFA.

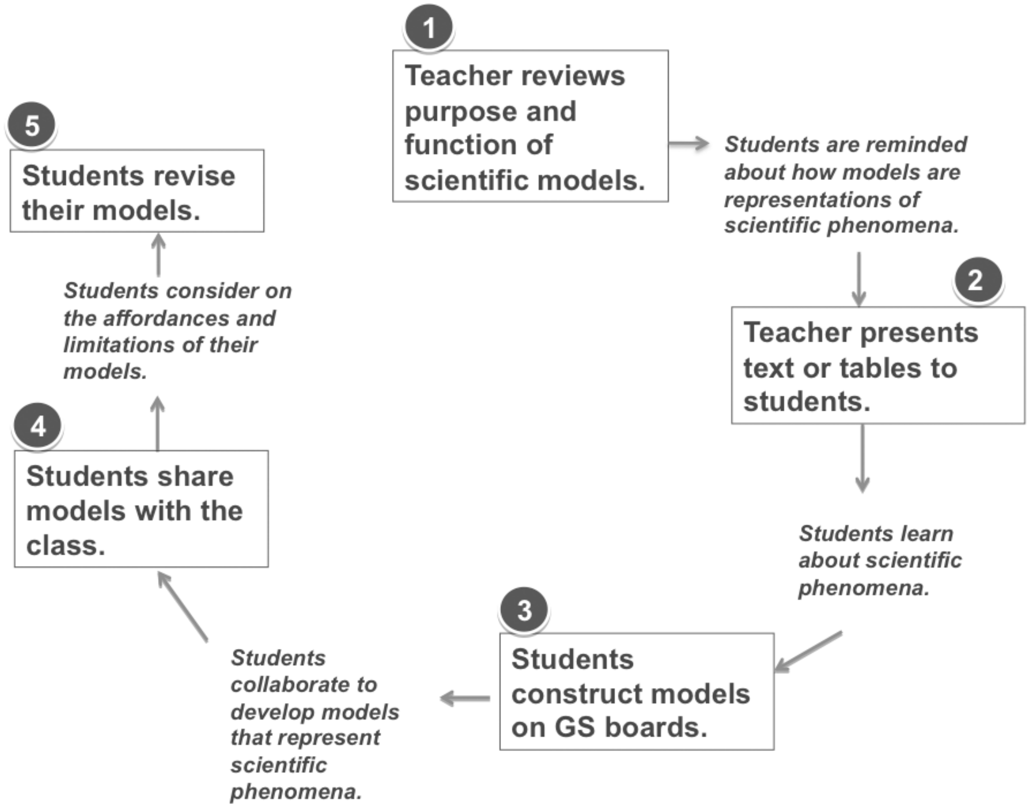

Figure 3. Model-based Reasoning: Constructing a Model *Routine*

In the Ring of Fire IFA, students explore an area in and around the Pacific Ocean, called the *Ring of Fire*, where large numbers of earthquakes and volcanic eruptions occur. This is due to the movement of the tectonic plates that exist in the area. The use of Group Scribbles as an interactive formative assessment space enables the teacher to "make thinking visible" by creating a public display of students' contributions to a map of the Ring of Fire. In this IFA, students use the tools in Group Scribbles to show and label the locations of volcanoes, earthquakes and plates in the Ring of Fire. The Ring of Fire IFA assumes that students have had some prior exposure to content on developing and revising models, the structure of Earth's interior, convection, and plate motion. This IFA is situated within an investigation in which students begin to explore relationships among events we observe on Earth's surface (e.g., earthquakes and volcanoes) and plate tectonics.

To enact this IFA, the teacher needs access to the Group Scribbles server, a teacher computer with web browser, a projector connected to the teacher's computer, and student computers with web browser and Group Scribbles. The teacher has teams of students conduct research on different aspects of the Ring of Fire (volcanoes, earthquakes, or plate boundaries). Teams use the internet and classroom text materials to research information regarding their assigned feature of the Ring of Fire. Each team creates a Group Scribbles board to showcase their learning. To facilitate discussion, the teacher can arrange the display to display multiple boards simultaneously. Examples of questions to promote discussion along with target responses are also included in the IFA, as shown in Table 2.

Table 2. Instantiation of Model-based Reasoning: Constructing a Model *Routine in* Ring of Fire *Interactive Formative Assessment (IFA)*

Steps in *Constructing a Model* Routine	Steps in *Ring of Fire* IFA
STEP 1. Teacher reviews purpose and function of models. The teacher prompts students about the features of models: (1) Models represent things that cannot be seen easily; (2) Model creation involves cycles of refinement as new evidence is gathered; and (3) Models are not perfect representations of phenomena.	Students are reminded that maps can be used to represent the location of Earth's landforms and that scientists use maps to understand the relationships among geologic phenomena that occur on Earth.
STEP 2. Teacher presents text or tables to students. The teacher can refer students to a textbook or web site or the text can be written in Group Scribbles (GS). Tables might be data tables from which students have to infer patterns that are created by some underlying phenomenon.	Students conduct research on their assigned topic (volcanoes, earthquakes, or plate boundaries).
STEP 3. Students construct models on GS boards. Students work in groups to construct a visual model representing scientific phenomena. Students might use evidence to create an appropriate model of changes in Earth's surface, create an accurate map of Earth's landforms, or create a reasonable model of dynamic Earth processes.	The teacher creates 3 GS boards [(1) Volcanoes, (2) Earthquakes, (3) plate boundaries] and uploads a background image of the map of the North Pacific Ocean and surrounding land masses. In their groups, students collaborate to find volcanoes, earthquakes or plate boundaries on the map. • Group 1 marks major volcanoes (using the red triangle stamp tool) and labels their locations by name and country using scribble notes. • Group 2 marks major earthquakes (using the blue circle stamp tool) and labels their locations and year of occurrence using scribble notes. • Group 3 draws major plate boundaries (using orange lines) and labels the plates they separate using scribble notes.
STEP 4: Students share models with the class. Each student group presents their model, and the teacher facilitates a discussion so that students can consider the affordances and limitations of their models. Questions posed by the teacher may include: • What about the Earth does this model present? • Why did this group place [Landform X] on this place in the map? *Continue until all groups have explained their reasoning.* • What's missing from this model that's important to the [change, landforms, process] we're discussing today? • How could this group improve their model?	The teacher can project each group's board or display multiple group boards at the same time. The teacher may ask the following questions: • Based on the various maps, what patterns do you see? **(Key idea: Earthquakes and volcanoes tend to follow the plate boundaries around the Pacific Ocean.)** • Using what you have learned in this unit's investigation as a guide, what is a *model* that could explain the patterns you see? **(Key idea: The co-occurrence of earthquakes and volcanoes in this region is explained by convergent plate boundaries, in which ocean crust subducts under continental crust and produces magma.)**
STEP 5: Students revise their models.	In their groups, students scribble on their boards a model for how volcanoes, earthquakes and plate boundaries are related..

Considerations in the Design and Implementation of Teaching Routines

Teaching routines can be a powerful resource in supporting instructional planning and decision making during instruction. However, there are some important considerations to take into account in the design of teaching routines.

Designing teaching routines

The identification of which process should be represented in a teaching routine is of critical importance, particularly because routines are intended to be used repeatedly by teachers and students. Well-designed routines will reflect processes that are essential to student learning in the domain and will articulate steps for how students can engage in the process through collaboration. In the domain of science, inquiry skills such as designing an experiment or creating and using models are examples of important processes that should be considered as the basis for teaching routines. Although developing an infinite number of routines representing different processes may be possible, it is not ideal. Rather, it is preferable to develop a smaller set of routines that are focused on critical processes and that can be used repeatedly in classes to engage students in appropriate ways of learning in a domain.

When considering the steps that should be represented in a teaching routine, we caution against over-specification. To enhance the applicability and use of routines with different content, steps are best written at a general level that provide guidance to the teacher about what to do next but also allow some flexibility in how they can be implemented. In addition, when routines overly constrain student interactions they potentially reduce authentic cognitive and social engagement and student motivation that naturally occur as a result of collaboration (Dillenbourg, 2002).

Designers of teaching routines must also attend to how classroom network technologies can be used to support student engagement in the steps of a routine. Particularly when teaching routines require collaboration, it is important that the technologies assist students in the types of communication and ways of thinking intended by the routine. When the technology is a poor fit, it may become a distraction for students and teachers. When the technology enhances students' ability to communicate and collaborate, greater learning gains should be possible (Krajcik, 2001).

Implementing teaching routines

Implementing a teaching routine requires moving from the generic steps in the routine to an instantiation of a routine in a lesson or assessment, which involves tailoring the routine to incorporate specific content. Care needs to be taken that the steps in the routine are adequately addressed, the content of the lesson is appropriate for the routine, and routines are appropriate for supporting students in achieving the desired learning objectives.

Using Teaching Routines to Design IFAs as a Professional Development Opportunity

In so far as teaching routines offer strategies to address complex interactions in the classroom, we view them as having great potential for professional development for teachers. We have conducted several workshops and teleconferences with teachers on teaching routines. A key feature of the professional development was to involve teachers as co-designers of IFAs with learning scientist researchers, assessment developers, and Earth scientists (Penuel, Roschelle, & Shechtman, 2007). The teachers involved in the design of these teaching routines were from the middle- and high-school in large urban school districts that include diverse student populations in terms of ethnicity and socio-economic status.

The co-design process with teachers first involved the unpacking of the IFAs drafted by the project team. Through this process the relationships among the teaching routines and the components of the IFAs were made explicit. To complete drafts of new teaching routines and IFAs, small groups worked collaboratively. Each group was assigned a range of expertise: a learning expert, an Earth science content expert, a teacher, a technology specialist, and a researcher. Not only did this activity result in the creation of IFAs for others to use; the act of design also was intended to be a form of professional development for participating teachers. By providing teachers with access to diverse expertise, we hoped to extend the range of what teachers could imagine was possible with the technology and the curriculum.

A key reason that we created teaching routines was to enable teachers to use them to design lessons on their own, as the need arises. The project's vetted IFAs are likely to be only one source of inspiration for teachers in doing so. By reviewing and unpacking routines embedded in IFAs, our intent is to provide teachers with the tools they will need to make the most of Group Scribbles technology. We have planned a series of professional development sessions (workshops and teleconferences) to identify ways that teaching routines can be incorporated effectively into classroom activities and to obtain feedback on the teaching routines and IFAs. Routines, as a structure, are abstract. To master their use and application, teachers will need examples of concrete instantiations of each routine before they will be ready to design their own routine-based activities.

To date, co-design teachers have reported that most teaching routines clearly articulate how the steps in the routines achieve the goals of enhancing communication, student participation and contingent teaching. In addition, teachers believe that the routines will help students learn high-level skills such as interpreting images, monitoring their understanding, designing experiments, and communicating specific information clearly. Several teachers predicted challenges related to classroom management, such as: (1) figuring out the "right amount of time" to allow students to answer questions, (2) keeping students on task during group work, (3) building in time for discussion and revision to each group's ideas, and (4) managing responses from multiple groups/individuals. As is common in design efforts, we anticipated that multiple cycles of testing and refinement of teaching routines and IFAs would be necessary.

FUTURE RESEARCH DIRECTIONS

Future research studies are planned to investigate further how often and reliably teachers integrate teaching routines in their instruction, how students of different backgrounds and attitudes perceive the IFAs and Group Scribbles technology, and how implementation varies for teachers with different levels of content knowledge and prior experience with using technology in their classrooms. These data on implementation will inform planning for revisions to the intervention in three ways. First, data will be used to identify additional technology support and training needs if teachers report that they experience significant difficulties that affect more than one to two students when they use Group Scribbles. Second, the data will be used to focus efforts to identify phases of instruction where teachers find it easier to use the teaching routines. Third, data from teaching routines and IFAs that were not successfully enacted will be analyzed to determine whether they need to be revised or eliminated, or whether additional training should be provided to teachers.

CONCLUSION

Teaching routines are designed to address some of the biggest barriers to using online classroom network technologies to collect and aggregate student data and make instructional decisions on the basis of those data. Teaching routines used in conjunction with classroom network technologies, such as Group Scribbles, have the potential to advance knowledge and understanding about classroom practices that build from research on student learning, assessment, cognitive science, and teacher learning to address major challenges to effective use of classroom network technologies. When instantiated as an IFA sequence in the classroom, teaching routines are intended to increase student opportunities to communicate with the teacher and with peers about their thinking, to motivate students to participate and learn from lectures, investigations, and readings, and to encourage student feedback to inform the teacher about how to adjust instruction.

One of the most important contributions of this approach is that teaching routines make explicit good teaching practices with classroom network technology. In the past, teaching has been described as a profession where practice is “privatized,” that is, where instructional decisions are largely left to individual teachers to make and where opportunities to observe colleagues teach are limited (Little, 1990; Lortie, 1975). Both accountability systems and efforts to promote opportunities for teachers to learn from one another, however, aim to expand the horizon of visible practice and bring teachers’ practice into closer alignment to improve student learning (Little, 2002, 2003; O'Day, 2002).

The process of making practice visible to peers is aided when teachers can develop a common language for describing their practice (Grossman & McDonald, 2008). In our work, that common language will be provided by teaching routines, and we expect it will serve not only as a resource for teachers to use to enable their own collaborative learning but also as a “boundary object” for anchoring discussions where researchers and teachers are both present and discussing how to improve a particular activity.

As specifications of sequences of an IFA, teaching routines can also serve as a resource for instructional design. In developing curriculum or in planning instruction, individuals and teams benefit from models for how to structure resources and opportunities for student learning (Gallagher & Penuel, 2009). To the extent that these resources instantiate principles of how people learn, these routines also make it more likely that the lessons developed will promote student learning. For example, teaching routines that embed into their designs what have been called “quasi-repetitive activity cycles” have been shown to familiarize students with the process of learning from reflection (Schwartz, Lin, Brophy, & Bransford, 1999; Vye, et al., 1998). The first time students encounter demands for reflection, they may not know how to learn from collaborative reflection; by repeating cycles of learning and reflection, though, students gain experience in learning from revising their own ideas in conversation with others.

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KEY TERMS & DEFINITIONS

Classroom network technology: technology that enables teachers and students to share questions, ideas, data, or responses via a local classroom network

Co-design: collaborative process in which researchers, teachers, and software developers design an educational innovation

Contingent teaching: adjusting instruction on the basis of particular patterns of student behaviour

Diagnostic question: question designed to elicit student preconceptions and relate student responses to known goal or problematic understandings related to the domain

Formative classroom assessment: a process that provides feedback to teachers and students about students' understanding and thus can be used to help teachers adjust their instruction to better address students' learning needs

Interactive formative assessment (IFA): a technology-supported formative assessment designed to promote student learning through the teacher's use of diagnostic questioning and contingent teaching techniques

Peer Instruction: an instructional approach in which a question is posed to students and students first develop their own response then work in small groups to reach consensus on a response

Teaching routine: a recurring, patterned sequence of interaction teachers and students jointly enact to organize opportunities for student learning in classrooms

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Dr. Christopher Harris is a researcher in science education at the Center for Technology in Learning at SRI International. His research interests include the design and study of science learning environments that capitalize on innovative technologies and make learning accessible for students of diverse backgrounds and abilities. At SRI, his research often involves practical work in K-12 classrooms and informal science contexts for the purpose of informing both research and practice. His recent publications have addressed science education policy, science assessment, design-based research of learning environments, inquiry-based teaching, and authenticity in science education.

Dr. Patricia Schank is a cognitive and computer scientist at SRI's Center for Technology in Learning, where she works with multidisciplinary teams to design, develop, and test innovative learning technology. At SRI, she has led the development of technology to support collaborative learning and online communities, software and curriculum to help students and teachers visualize nanoscale phenomena, and simulation-based assessments to measure science learning. Her recent publications have addressed participatory design, computer-supported collaborative learning, and analysis of online educator networks.