Should science learners be challenged to draw more? Certainly making visualizations is integral to scientific thinking. Scientists do not use words only but rely on diagrams, graphs, videos, photographs and other images to make discoveries, explain findings, and excite public interest. From the notebooks of Faraday and Maxwell (1) to current professional practices of chemists (2), scientists imagine new relations, test ideas, and elaborate knowledge through visual representations (3–5).

However, in the science classroom, learners mainly focus on interpreting others’ visualizations; when drawing does occur, it is rare that learners are systematically encouraged to create their own visual forms to develop and show understanding (6). Drawing includes constructing a line graph from a table of values, sketching cells observed through a microscope, or inventing a way to show a scientific phenomenon (e.g., evaporation). Although interpretation of visualizations and other information is clearly critical to learning, becoming proficient in science also requires learners to develop many representational skills. We suggest five reasons why student drawing should be explicitly recognized alongside writing, reading, and talking as a key element in science education. We offer distinct rationales, although in practice any single drawing activity will likely rest upon multiple justifications. Both old and new technologies offer exciting opportunities. We conclude by highlighting important questions yet to be answered and key future research to extend the current professional practices of teaching and learning (7–9).

Drawing to Learn to Represent in Science
Students need to learn how scientists use multiple literacies of this subject to construct and record knowledge, where reading, writing, and talk are integrated with visual modes (11–13). Generating their own representations can deepen students’ understanding of the specific conventions of representations (e.g., “This is how a line graph works.”) and their purposes (e.g., the effectiveness of line graphs for showing continuous quantitative information), as well as how representations work more generally (e.g., a representation is better when it is coherent, compact, and parsimonious) (3, 14, 15). Teachers can guide students to acquire the visual literacies of science at the point where they will see their relevance and appreciate their explanatory power (16).

Drawing to Reason in Science
To show conceptual understanding, students must learn how to reason with multiple, often visual, modes (9). Understanding sound waves, for instance, can involve being able to coordinate a range of wave diagrams, time-sequenced representations of air particle movement, and pressure variation. Different representations have distinctive attributes that both guide and constrain what learners do and come to understand (17–19). As they select specific features to focus on in their drawing, learners reason in various ways, aligning their drawing with observation, measurement, and/or emerging ideas (6, 20). Practice in flexible manipulation of representations has been argued to be central for developing expertise (21). Classroom research shows how students reason as they generate and refine models supported by expert teacher guidance (22, 23). This creative reasoning is distinct from, but complementary to, reasoning through argumentation (24).

Drawing as a Learning Strategy
Effective learning strategies help learners overcome limitations in presented material, organize their knowledge more effectively and integrate new and existing understanding; ultimately, they can be transformative by generating new inferences (25, 26). Drawing can be one such effective strategy (6, 27).
For example, asking learners to read a text and draw what they have understood requires them to make explicit this understanding in an inscrutable form ([28] see fig. S1 in supporting online material (SOM)). Unlike other constructive strategies, such as writing summaries or providing oral self-explanations, visual representations have distinct attributes that match the visual-spatial demands of much of science learning. Moreover, visual representation has been shown to encourage further constructive strategies (29). Inventing representations (including drawings) acts as preparation for future learning, because it can help students discern key features and challenges of new tasks (30).

**Drawing to Communicate**

Scientists draw to clarify ideas for colleagues, students, and the public (2, 5). In externalizing private knowledge more permanently, visual representation is one way to enable broader dissemination (4). Through drawing, students make their thinking explicit and specific, which leads to opportunities to exchange and clarify meanings between peers (31). Where learners generate and publicly share their representations, they learn by critiquing the clarity, coherence, and content of what they and their peers have drawn (32). These windows into student thinking can serve teachers in diagnostic, formative, and summative assessment (33, 34) (fig. S2).

**Current Programs and New Directions**

Various programs featuring drawing are now in progress (22, 23, 35). The Role of Representation in Learning Science (RiLS) project (36) is an exemplar showing how, through hands-on activities and a variety of multimodal representations in which drawing was central, learners aged 10 to 13 were guided to generate, justify, and refine representations in science (fig. S3).

In a unit on water, students produced representations of particle ideas beyond the teachers’ experience of previous performance. For example, in one task, a class of students placed their wet hands on paper and then were challenged to represent what happens as the handprint diminishes. The drawings reflect learners’ expanding on previous work to reason about particle distribution and movement, energy exchange, and time-sequencing (see the figure) (Fig. 1). Students’ visual choices indicate thoughtful engagement with the task of creating a coherent account of the phenomenon. Through appraisal and refinement of drawings, teachers and students established some representation conventions, such as the circles reflect-