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The Promise and Practice of Learner-Generated Drawing: Literature Review and Synthesis

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This article explores learner-generated drawing, a strategy in which learners construct representative illustrations in support of learning goals. Both applied and empirical literature is reviewed with the purpose of stimulating research on this strategy. Clear from this review is the gap that exists between prescriptive readings on learner-generated drawing and research-based understandings. To make sense of inconsistent empirical evidence, the research review is organized around a series of hypotheses grounded in current understandings of cognitive and strategic processing. A theoretical framework for understanding the drawing strategy is proposed by extending R. E. Mayer's (1993) theoretical processes of selection, organization, and integration. The framework is intended to guide and organize future research efforts and, to that end, earlier proposed hypotheses are incorporated into the explanatory constructs of this theoretical perspective. The article concludes with a discussion of how strategy instruction might play a role in the effectiveness of the drawing strategy.

KEY WORDS: drawing; learning strategy; comprehension strategy; cognitive processes.

A hallmark of sophisticated, expert-like performance is the ability to think flexibly and to transfer knowledge across contexts. In part, this process is reliant on an underlying cognitive structure in which knowledge is integrated across varying representations (de Jong and Ferguson-Hessler, 1986; Silver, 1979), representations either within or between modalities

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(Van Someren *et al.*, 1998). When a student can translate a data table to a linear function (Haverty *et al.*, 2000) or use illustrated text to solve transfer problems (Mayer and Sims, 1994), that student is assessed as functioning at a higher level relative to a student who struggles with these activities. As critical as integration is, learners have a difficult time working with more than one format and integrating verbal and nonverbal representations of complex content (e.g., Scanlon, 1998; Tabachneck-Schiif and Simon, 1998). Given both the value and challenge of this process, strategies that facilitate the integration of different representations, particularly those that cross modalities, have great potential for improving student learning. Learner-generated drawing is one such strategy because drawing involves the construction of an internal, nonverbal representation that is mapped onto elements of the alternative, provided representation. The purpose of this article is to make the case that learner-generated drawing is a strategy that warrants thorough, systematic study.

Although learner-generated drawing received some attention in the mid to late 1970s, research interest dried up by the mid 1980s. We believe the loss of interest is partially attributable to inconsistent findings and a body of research which, on balance, is rather disappointing. Along with the obvious value briefly stated above, there are two additional reasons for renewing interest in learner-generated drawing. First, an abundance of prescriptive publications available to classroom teachers tout learner-generated drawing as a strategy that can meet a number of educational objectives. This is true despite a lack of evidence to support most applications. It is not that these prescriptions are necessarily wrong; rather, the research evidence addressing drawing as a learning process is inconsistent, silent, or qualifying. To highlight the distance between research and practice, the review section of this article begins with an overview of the applied literature before synthesizing the empirical research. We hope the juxtaposition of an array of implementations against scant research evidence will stimulate a systematic program of research to close the gap between recommended practices and empirical support.

Our second reason for stimulating this research line is embedded throughout our review of research and presented in full in the final section of the article. Specifically, we believe that current understandings of cognitive and strategic processing can be applied to analyze the inconsistencies of past research and to develop a series of testable hypotheses. To achieve this, the research review is organized around a set of three hypotheses. These hypotheses demonstrate that findings once thought confounding are actually quite predictable. Finally, the theoretical model proposed in this article is included as a framework which can guide and organize a systematic research effort. Notwithstanding the importance of applied research questions for their own sake, this framework is necessary for the development of a cohesive body of research.

Before these objectives can be accomplished however, the meaning of "learner-generated drawing" must first be more carefully defined. To this end, the following section is dedicated to clarifying the definition of the learner-generated drawing strategy as it is considered in this article.

LEARNER-GENERATED DRAWING: STRATEGIC, REPRESENTATIVE, AND CONSTRUCTIVE

Although specific objectives and drawing methods vary across implementations, learner-generated drawing is defined as a strategy in which learners construct drawing(s) to achieve a learning goal. Drawing is considered a strategic process because it matches several dimensions along which strategies are defined: learner-generated drawing is goal-directed, serves to organize knowledge, and, when matched to the task, improves learning (Paris *et al.*, 1983). As such, learner-generated drawing is similar to other strategies such as summarization, self-questioning, or prior knowledge activation. As a strategic process, the behavior of producing a drawn, external representation is believed to direct underlying cognitive processes responsible for task performance (Van Meter, 2001). Because these internal processes play a critical role in both the definition of drawing and the literature reviewed in this article, these processes are outlined briefly in the following paragraphs. A deeper examination of these cognitive processes appear in the final section of this article.

Imagine a hypothetical student reading to learn about the system of a bird's wing. This student is instructed to make a drawing to represent the important parts of the wing and show how these parts fit together. The student begins the task by reading the text and forming an internal, verbal representation of the text's meaning by first selecting and then organizing elements presented in the text (e.g., Mayer and Gallini, 1990). Direct activation of previously stored concepts facilitates comprehension and further activates stored knowledge to support inferencing processes (Graesser and Goodman, 1985).

As the learner begins the drawing task, referential links between concepts contained in the verbal symbolic representation are used to activate stored nonverbal representations (i.e., imagens; Paivio, 1991). Just as the verbal representation is organized, the nonverbal representation is organized via associative links between stored imagens. Given the nature of the task, elements of the nonverbal representation are mapped onto corresponding elements of the verbal representation. Specifically, when the drawing is based on a description given in some alternative format, drawing demands not only the construction of an internal, nonverbal representation but also the integration of the nonverbal and the alternative representation. This mapping process is necessary for the integration of representations (de Jong *et al.*, 1998) and is likely a critical process for determining the effectiveness of drawing. With respect to these cross-representational integrative processes, there are important differences between drawing construction and verbally-based strategies such as matrix notes or flow charts. Although these latter strategies may guide learners to organize verbal representations, they do not require the integration of representations, particularly those that cross modalities.

In sum, the definition of drawing used in this article is directed and constrained by the hypothesized underlying cognitive processes involved. Specifically, drawing involves constructive learning processes that engage nonverbal representational modalities and requires integration. The relationship between these processes and the selection of literature reviewed in this article is explicated further in the remainder of this section. Admittedly, this article emphasizes the integration of internal verbal and nonverbal representations. That is, the learning process involved when drawing in response to provided, verbal material. This emphasis is not intentional but results from the nature of the articles reviewed. The ideas presented in this article are generalizable to contexts in which learning materials are not in a traditional verbal format (e.g., science observations; Steele, 1991).

The phrase "learner-generated drawing" demands explanation of what is meant by both "drawing" and "learner-generated." Drawing might refer to many different activities including drawing as artistic expression, demonstrating knowledge, or learning the techniques of other artists, in this article, drawing is limited to representational drawings where the definition of representational drawing is parallel to the definition of representational pictures (e.g., Carney and Levin, 2002). Specifically, representational pictures "share a physical resemblance with the thing or concept that the picture stands for" (Alesandrini, 1984, p. 63). Applied to drawing, representational then means that the drawing is intended to look-like, or share a physical resemblance with the object(s) that the drawing depicts.

Excluded from our discussion, then, are nonrepresentational constructions such as schematics to diagram features of a geometry problem and maps to detail land formations. With these formats, the intent is the depiction of important elements but not in a form that replicates the physical appearance. The reason for excluding these formats is because the hypothesized underlying cognitive processes likely differ from those that underlie drawing construction. We base this assertion on the conclusion that the interpretation of different representational formats requires different cognitive processes. Diagrams, for example, engage different cognitive processes compared to verbal explanations of the same content (Larkin and Simon, 1987). Furthermore, two different representations that are informationally equivalent usually do not have equivalent computational efficiency because the interpretation of different representational formats requires different operators (Boshuizen and Tabachneck-Schiff, 1998).

If different inferential processes are required for the *interpretation* of varying formats, it is logically concluded that different processes are required for the *construction* of these formats as well. Given that a major objective of this article is to organize and focus the study of learner-generated drawing, it is important not to knowingly intermingle strategies that differ along critical dimensions. As a result, we focus only on the construction of drawings that can be classified as representational.

The same reasoning is applied to our decision to exclude the literature on computer-aided graphic generation. Research comparing learner processing in traditional and computer-aided contexts illustrates that the addition of the human–computer interaction alters processing. For instance, Murphy *et al.* (2003) demonstrated that learners process text differently when it is presented on a computer compared to traditional paper presentations. Of particular concern is the potential, in a computer-assisted task, for the computer to execute important transformational process for the learner (Kozma, 1991). In traditional contexts—those contexts included in this review—the operations required for drawing rest entirely on the learner. This concern is consistent with Kozma's (1991) position that the specific media used interacts with learner processing, influences how learners represent information, and may result in outcome differences.

Subsequently, this article is limited to a discussion of representational drawings with hypothesized cognitive processes grounded in dual coding theory (Paivio, 1986, 1991). Specifically, when required to draw, a learner first generates an internal representation of the provided, alternative representation. The concepts included in this representation are used to activate, via referential links, the corresponding imagens. Activated imagens then give rise to the experienced image. The external drawing is the learner's attempt to depict on paper the image experienced internally. A nonrepresentational depiction, on the other hand, requires additional processes. Specifically, the image of the object as it appears physically is translated into the conventional format required by the representation.

To illustrate these differences, imagine the task of drawing a map of a mountain trail. As a representational drawing, the map resembles a photograph. Changes in elevation are illustrated by drawings of peaks in relation to one another. In a nonrepresentational depiction, however, the image of the peaks is translated into conventional topographic lines. Clearly, the latter construction requires domain-specific knowledge of the convention and an understanding of how to create these lines; the image of the peaks must be translated into these lines.

Despite our efforts at delineating the categories of representational and nonrepresentational, gray areas remain. For example, although both a drawing of rock layers and a graph of sediment formation against time can be easily classified as representational and nonrepresentational, a map of this same area is less clearly classified. The map has some qualities of a representational drawing with objects accurately drawn to depict spatial relations, land shapes, and so on. Other aspects, however, are nonrepresentational. In addition to topographic lines, for instance, blue lines indicating rivers, black lines indicating trail paths, and iconic symbols representing physical structures are just a few examples of nonrepresentational conventions used on a map. In summary, a representational drawing is defined as one in which the learner intends to construct on paper a picture that replicates the image in the mind.

A similarly gray area arises when establishing the meaning of "learner-generated." Learner-generated means that the student is the primary causal agent in the construction and/or appearance of the drawing. This construction process, however, rests on a continuum. The learner-generated end of the continuum is anchored by drawings the student constructs free hand using only tools such as blank paper and pencil. With these drawings, the student is solely responsible for both the construction and the appearance of the final product. The opposite end of the continuum is anchored by provided representations such as illustrations, object drawings on which students provide verbal labels, and verbal text supplements.

In the middle of this continuum are techniques in which some portion of the representation is learner-generated and some portion is provided. This includes, for example, methods in which component pieces of the representation are provided and the learner organizes these into a coherent, accurate representation of to-be-learned content (e.g., Britton and Wandersee, 1997; Lesgold *et al.*, 1975). In selecting literature for this article, the definition of learner-generation required that the learner control the final appearance of the pictorial representation.

In sum, the learner-generated drawings discussed in this article are defined as pictorial representations (a) that are intentionally constructed to meet a learning goal, (b) that are meant to depict represented objects accurately and, (c) for which the learner is primarily responsible for construction and/or final appearance.

Having defined learner-generated drawing, the stage is now set for a review of the relevant literature. As indicated at the outset, we believe it is important to not only be aware of the empirical research but also to understand the mismatch between the conclusions warranted by the empirical evidence and the classroom applications abundant in the literature. To this end, the literature review begins with a sampling of some of the drawing applications and claims found in the applied, practitioner-oriented literature.

LEARNER-GENERATED DRAWING: A REVIEW OF THE LITERATURE

Classroom Applications of Learner-Generated Drawing

For the purposes of this article, applied, practitioner-oriented articles are those that address how drawing should be used in the classroom to improve learning or instruction. In searching the literature, we operationally defined these articles through a combination of the author's intended audience, an emphasis on the description of instructional techniques, and the publication outlet. Articles for this section were obtained through searches of the electronic databases ERIC and PsycInfo and through hand searches of popular practitioner-oriented journals (e.g., *The Reading Teacher, Instructor, Arithmetic Teacher*, and *Teaching K – 8*, etc.). Given the number of candidate articles located, this review is not exhaustive. Instead, a sample of 15 articles representing a range of educational objectives were selected. A summary of these articles is shown in Table I. The review of these articles is organized according to the claims made with respect to what learner-generated drawing can achieve in the classroom.

Drawing Improves Observational Processes

In the sciences, learner-generated drawing has been promoted as a strategy to improve students' memory, observational processes, and imagination (Steele, 1991; Stein and Power, 1996). Consistently, Dempsey and Betz (2001) recommend a system for teaching students to use drawing as a strategy to improve observational processes. Altogether, this drawing system employs five exercises, presented over 5 days. As an example, one of these exercises, intended to improve attention to detail during observations, has students observe an object and draw it from memory. Another exercise has pairs of students sitting back to back. One student looks at an object and describes it while the other student attempts a drawing based on the verbal description. Dempsey and Betz believe the verbal communication necessary to complete this exercise helps students learn descriptive terms

Table I. Summary of Articles That Document Drawing Strategy Use in the Classroom

Author	Objective	Drawing application	Student age/ grade level	Content area
Britton and Wandersee (1997)	Learning complex biological processes	Manipulate illustrations into correct sequence, draw missing steps	Unspecified	Science (biology)
Caldwell and Moore (1991)	Improve prewriting and planning skills	Draw to represent story element; use peer feedback to revise drawing, followed by period of writing	Second and third grade	Language arts (composition)
Constantino (1986)	Understand story and text structure	Draw character before and after change; drawings support memory and learning, and facilitate discussion	Elementary school	Language arts (comprehension)
Dempsey and Betz (2001)	Improve observational skills	Five successive exercises to build drawing skill; teach value of drawing for science learning	High school	Sciences (biology)
Dietz (1976)	Improve creativity and expression in composition	Collaborate to draw main idea; individual drawings to elaborate main idea; drawings facilitate generation of ideas for writing	Fourth grade	Language arts (composition)
Fisher (1976)	Improve listening comprehension	Teachers and students illustrate key elements in narrative story; students draw story events	Elementary school	Language arts (comprehension)
Freeport Area School District (SEEH) (1976)	Improve observational skills	Observe small section of nature and enlarge in drawing; search and draw shapes in nature	Unspecified	Science
Hubbard (1997)	Assist transition from oral to written forms of expression	Write and illustrate stories; use drawing to depict ideas unexpressable in written form; use drawings for planning and discussion	First grade	Language arts (composition)

Johnson (1988)	Learn language rules	Read then illustrate meaning of rule; drawing presented to class, hung on wall for memory support	Unspecified	Language arts (grammar)
Karnowski (1986)	Assist transition from oral to written forms of expression	Draw at activity centers throughout classroom	Preschool	Language development
McConnell (1993)	Improve expository text comprehen-sion	"Before" drawings activate background knowledge, serve as comparison with "after" drawings; facilitate discussion and other strategies	Adult	Language arts (basic literacy)
Moore and Caldwell (1993)	Improve prewriting and planning skills in composition	Draw to represent story element; use peer feedback to revise drawing, followed by period of writing	Second and third grade	Language arts (composition)
Rich and Blake (1994)	Improve com-prehension, integrate text with prior knowledge	Draw main idea; supplement drawing with writing	Fourth and fifth grade	Language arts (comprehen-sion)
Steele (1991)	Memory training, improve observational skills	Observe specimen and draw from memory	Unspecified	Science
Stein and Power (1996)	Acquire science knowledge	Imagine and draw water molecule under microscope; complete successive drawings throughout unit	High school	Science

and properties. In a third exercise, rubbings are used to help students learn about the characteristics of texture and surface of observed objects. The five exercises in this system build on one another so that students learn how to use drawing as a strategy for science learning. Dempsey and Betz argue that drawing is a useful strategy because it helps learners see the details and subtle properties that distinguish to-be-learned scientific specimens—a skill critical in scientific study.

Similar applications are found in The Sandburg Environmental Educational Handbook (Freeport School District, 1976). In one activity, students begin with basic shapes such as a circle, square, or triangle and look at nature to find these shapes in different objects. Each found object is then drawn on a piece of paper next to a simple line drawing of the basic shape that was observed within it. A second set of activities is designed to "instill habits of closer observation and awareness" (Freeport School District, 1976, p. 5). One of these specific techniques instructs students to "study closely a small section of nature" (p. 5). Students then make an enlarged drawing of 1 $in.^2$ of the observed object with this activity forcing attention to details and specifics.

Drawing Supports Acquisition of Content Area Knowledge

In social studies, the sciences, and language arts, recommendations are offered for using drawing to direct learners' attention to illustrations, stimulate the use of imagery and visualization, and increase content area knowledge. Britton and Wandersee (1997), for example, describe a drawing strategy used to help advanced students learn biological processes. In this biology class, students read to learn about biotechnology procedures such as the polymerase chain reaction. The teacher cuts up illustrations that show different aspects of the procedure while the students read. Students then work together to organize the illustrations and place them in the correct sequence. With the provided illustrations ordered, students identify missing steps and construct drawings to complete the chain. Britton and Wandersee claim these drawings engage students in higher level thinking and support a deep understanding of the material. Britton and Wandersee believe there is an additional benefit to using this strategy: by listening to student dialogue during drawing, teachers can determine how well students understand the content and if any misconceptions are developing.

Stein and Power (1996) also advocate drawing as both a tool for learning and a means to express knowledge. Stein and Power describe how drawing was implemented in a high school science class. To assess prior knowledge, the teacher instructed students "to draw what they would see if they were looking at water through a superpowerful microscope" (p. 66).

Over the course of the unit, students made additional drawings. Improvements in the quality of these drawings reflected student learning. Stein and Power credit drawing in this classroom with the ability to force "students to think" (p. 66). The classroom teacher also used students' drawings as an informal assessment tool to identify and address learners' misconceptions.

Learner-generated drawing has also been used to support the acquisition of knowledge in language arts. As an example, Constantino (1986) describes a lesson in which elementary school students use drawing to learn the compare–contrast text structure. The lesson begins with a story-based homework assignment in which students construct drawings of a character both before and after undergoing a personality change. Constantino uses these drawings as concrete referents to teach the compare–contrast structure, prompt student memory during discussion periods, and generate group questions about the compare–contrast structure. Constantino claims that, in addition to acting as an effective learning tool, these drawings motivate students to complete the drawing task more than would traditional written comprehension questions.

Johnson (1988) also uses learner-generated drawing in the language arts classroom. In the drawing method she describes, students first read about a language rule. After reading, students create posters to illustrate the meaning of the rule, in Johnson's use of drawing, students are instructed to incorporate writing by including explanatory words from the text. Completed posters are presented to the class and students explain how their drawing represents the rule. Posters are displayed on classroom walls to remind students of the rules during subsequent writing assignments.

Drawing Improves Text Comprehension

With text comprehension as the objective, various applications of drawing techniques have been credited with activating background knowledge, supporting the use of other strategies, and increasing the knowledge acquired from text. An interesting trend that emerges from these applications is that drawing strategies are especially credited for assisting young and remedial readers. As an illustration, Fisher (1976) discusses drawing as a means to improve elementary-aged remedial readers' listening comprehension. While reading the story, the teacher stops at certain points and begins the outline of an illustration. Students are called upon to take turns filling in this illustration, in the provided example, students are listening to a story about a king and queen who wish to have a child. While the teacher draws an outline of the characters, the children draw facial expressions to show the king and queen's emotions throughout the story.

Fisher (1976) uses this process to engage students in the story and discuss different story parts. Although the lesson described has a great deal of teacher control over the illustration, drawing is also used in more independent ways; students sometimes free draw illustrations or organize cutout pictures to create picture books of the story (Fisher, 1976). Much like Constantino (1986), Fisher believes that learner-generated drawing not only improves comprehension but also increases student involvement.

Similarly, Rich and Blake (1994) describe using drawing with fourth and fifth grade remedial readers to improve both text comprehension and knowledge acquisition. Students in these classrooms are taught to use drawing to represent main ideas and to combine drawing with words. In addition, Rich and Blake indicate this strategy can be used before reading to activate background knowledge and to prompt discussion. Students can also construct drawings after reading as a strategy for integrating ideas across the text. Rich and Blake make the important point that the drawing strategy was relatively easy to learn; students employ this strategy effectively after only one teaching session.

Learner-generated drawing was used in an adult basic literacy class (McConnell, 1993). In the described scenario, students construct drawings to learn from a text about rainforests. To begin, a brief introduction of the topic is given and students create "before" pictures of a rainforest. These drawings then provide the basis for a group discussion as students identify similarities and differences across drawings. Following this activity, students read expository text about rainforests and then construct new drawings. In making these "after" drawings, students revise as needed to render a more accurate representation. Drawings are then shared and used to discuss what was learned. Students are directed to compare before and after drawings, using this comparison to clarify what was learned. McConnell also uses learner-generated drawing to support other comprehension strategies. For example, she has her students compare drawings to find and list features repeated across drawings. Students then construct concept maps using these features as to-be-mapped concepts.

Drawing Facilitates the Writing Processes

In writing, drawing is seen as a means to stimulate students' thoughts during story formation (Dietz, 1976), as an aid during revision (Ernst, 1997a), and as a support for "detailed and descriptive writing" (p. 26, Ernst, 1997b). Additionally, many believe that drawing supports young students in making the transition from oral to written forms of expression (e.g., Hubbard, 1987; Karnowski, 1986).

Learner-generated drawing has been specifically used to help students generate story ideas and plan writing activities. Dietz (1976), for example, had fourth grade students in her classroom generate drawings to spur imagination and to express these ideas in writing creative essays. To explain how she uses this strategy, Dietz describes an activity in which students were to invent and write about a monster. The activity began with students participating in a group creation and drawing of a class monster. With ideas flowing, students then made individual drawings of imagined monsters. Drawings were accompanied by written descriptions and stories about the monsters. Dietz contends this strategy helps students generate novel ideas for writing and promotes other literacy activities in the classroom (e.g., writing letters from one monster to another, reading books about monsters, etc.).

Caldwell and Moore (1991) used drawing as a planning strategy for writing. This strategic prewriting activity begins with a 15 min whole class discussion about a story element (e.g., character, setting, description, etc.). Following the discussion, students warm-up by drawing pictures representative of the discussed story element. Ideas for stories are formulated during the remainder of the 45 min session as students draw story boards and discuss ideas with other students. Drawings are used to generate ideas, get feedback from others, and make changes before writing. This planning period is followed by an extended writing period.

Unlike the other articles cited in this section, Moore and Caldwell (1993) also collected data to compare the efficacy of drawing to other prewriting strategies. Over a period of 15 weeks, the quality of written products for students using the drawing strategy, drama, or a more traditional write-and-revise strategy was compared. During the first 5 weeks, students in the draw group exhibited greater variance in the quality of written products than the traditional group. By the end of the 15 weeks, however, both the drama and draw groups were producing better written stories than the traditional writing group. Moore and Caldwell concluded that learner-generated drawing was an effective prewriting strategy. Drawings facilitated thought organization and were easier to edit than writing.

It is also contended that drawing supports young learners as they transition from oral to written language. For these young learners, the expression of words in the symbolic form of writing is unfamiliar and challenging. Drawing, because it is concrete and familiar, may support these learners during early writing tasks. Karnowski (1986), for example, observed preschool children as they interacted at the classroom writing center. She found that young children used drawing extensively, both to explain and to elaborate writing. Another example is Hubbard's (1987) description of a first grade classroom. In this classroom, students are encouraged to create illustrations for written stories and to use drawing to show what cannot be expressed in words. Furthermore, in this classroom, drawings are used for planning and as the basis for story discussion.

Drawing Improves Student Affect

A fairly consistent assertion throughout the applied literature is that drawing activities positively influence students' affective processes (Biller, 1994; Constantino, 1986; Moore and Caldwell, 1993). Specifically, drawing is credited with stimulating interest in target content (Ernst, 1997c), increasing levels of involvement with this content (Johnson, 1988; McConnell, 1993), and engaging learners in higher-order thinking (Britton and Wandersee, 1997). Several authors also propose that these effects are particularly important for remedial readers (Fisher, 1976; Rich and Blake, 1994). A strategy that sustains motivation and acts as a performance support greatly benefits struggling readers.

It is unfortunate that few of the claims cited in this section can be supported by research. This is not because empirical evidence conclusively contradicts these assertions but because little research has investigated drawing as a learning strategy. Further, because this issue has not been pursued systematically, the existing body of research contains varying methodologies. As a result of both methodological variance and the limited number of studies conducted, it is difficult to resolve the inconsistencies in the empirical literature or the contradictions between empirical results and practitioner claims. The following section reviews the empirical evidence in an effort to determine the effectiveness and benefits of learner-generated drawing and to provide an organization to this literature that may influence the direction of future research. Unfortunately, because there has not been a tie between questions pursued by research and claims made in the applied literature, it is not possible to organize the empirical review around the educational objectives covered in the article thus far. The two bodies of literature are integrated, however, as educational objectives are revisited throughout the review of research.

Empirical Research on Learner-Generated Drawing

The lack of any systematic program of research on student-generated drawing presented challenges for locating studies appropriate for inclusion in this review. As is common, we began our literature search with the electronic databases ERIC and PsycInfo but these search systems were of little use. For example, when "drawing" and "learning" were entered as ERIC keywords, 1,985 references appeared. Our concern with this number, however, was neither the volume nor the appearance of a large percentage of inappropriate sources. Rather, our concern was that this net failed to capture several sources known to be appropriate (e.g., Hall *et al.*, 1997; Snowman and Cunningham, 1975). Accordingly, alternative search strategies were employed including hand searches of journals in which other drawing studies had appeared, name searching the authors of located articles, and culling reference sections of previously located articles. Thus, although our intent was to present an exhaustive review of the extant literature, admittedly, it is possible that some relevant articles were overlooked. A summary of the 15 studies comprising the review is included in Table II.

To organize this section in a meaningful way, articles were examined for common patterns in methods and results. The result was a set of three hypotheses that emerged from this body of work. We use the term hypotheses intentionally here to reflect the tentative nature of assertions that are based on only a small number of studies that have wide variation in methods, target content, outcome assessments, and participants. Our confidence in these assertions is bolstered, however, because each is upheld by existing literature and is consistent with current models of cognitive and strategic learning processes. Clearly, however, we believe each hypothesis requires further exploration. The three hypotheses are:

1. The accuracy of constructed representations is predictive of performance on outcome assessments.
2. Learners require support to use drawing effectively.
3. Higher-order, but not lower-order, assessments are sensitive to the effects of learner-generated drawing.

The Importance of Drawing Accuracy

In every study that has scored drawings for accuracy, a significant positive correlation was obtained between accuracy and posttest performance. Although specific scoring methods differ across studies, accuracy is defined as the degree to which completed drawings resemble the represented object(s). For example, Van Meter (2001) used a 4-point rubric to classify drawings according to the amount and sophistication of structural and systematic knowledge depicted in the drawing.

The positive correlations between drawing accuracy and performance are found when constructed drawings serve as either a memory aid (e.g., Butler *et al.*, 1995) or a study strategy (e.g., Lesgold *et al.*, 1975; Van Meter, 2001). Greene (1989), for example, demonstrated that participants performed better on posttests when drawings accurately depicted text

TABLE II. Summary of Empirical Studies Using the Drawing Strategy

Author	Drawing conditions	Material	Sample	Assessment	Findings	Benefit?
Alesandrini (1981)	Read; write, or draw under holistic, analytic, or no instructions and read-twice control	Chemistry text	College	Multiple-choice (factual, comprehension, application)	Main effect of drawing; drawing-holistic group higher than writing-analytic group or writing-no instructions group; all drawing groups higher than control	Yes
de Bock *et al.* (1998, Exp. 2)	Math word problems; no instructions, draw, or draw with provided drawing	Mathematics word problems	High school	Mathematics, word problems	Drawing not better overall; more likely to correctly answer if drawing was made	Yes
Greene (1989)	Read; choose to write, draw, or diagram to represent relations; drawings available as memory aids	Hierarchical text relations	Second, fourth, sixth grade	Concept identiciation, reasoning	Accuracy and test performance positively correalted; sixth grade students did not choose drawing	Yes
Hall *et al.* (1997)	Read; draw with no illustrations, read with provided illustrations or read with no illustrations; draw participants told what to draw	Mechanical systems text	College	Problem solving	Draw and provide illustrations group higher than control group; no difference between drawing and provided groups	No
Lansing (1981)	Observe model; observe, trace with finger, draw, two controls	Two- dimesional model	Kindergarten	Model drawing; distractor test	Draw group higher on distractor test	Yes
Lansing (1984)	Observe model; pencil draw (two or six practice sessions), pencil draw with instructions, small or large paintbrush	Two-dimesional model	Kindergarten	Model drawing; distractor test	No significant difference on distractor test; grain scores for all drawing groups higher than nondrawing groups from Lansing (1981)	Yes

Lesgold *et al.* (1975, Exp. 1)	Listen to stories; half use cutout manipulatives of characters and scenes to draw; distractor manipulatives	Narrative text	First grade	Free recall	Nondrawing control group recalled more story propositions; accuracy positively correalted with number of propositions recalled	No
Lesgold *et al.* (1975, Exp. 2)	Replication; distractor manipulatives removed	Narrative text	First grade	Free recall	Drawing group recalled more story propositions	Yes
Lesgold *et al.* (1977)	Listen to stories; half use cutout manipulatives of characters and scenes to draw; only relevant manipulatives; varied length and complexity of stories	Narrative text	First grade	Literal questions; free recall	Drawing group scored higher on both measures regardless of length or complexity; more likely to recall inaccurately drawn propositions than omitted propositions	Yes
Rasco *et al.* (1975)	Read; draw or drawing provided; half participants told to image	Mathematics text	Fourth and fifth grade	Multiple-choice (verbal knowledge)	Drawing group not significantly higher than provided drawing groups overall	No
Snowman and Cunningham (1975)	Read; write or draw to adjunct prompts, read only control	Expository text	College	Factual recall	Writing group scored highest overall; drawing group higher than control group	No
Tirre *et al.* (1979)	Read; write or draw concept relating objects; concrete or abstract science text	Science text	College	Multiple-choice and production (relationships)	Writing group scored highest overall	No

TABLE II. Continued

Author	Drawing conditions	Material	Sample	Assessment	Findings	Benefit?
van Essen and Hamaker (1990, Exp. 2)	Math word problems; draw or control; three drawing training sessions with discussion and provided drawings	Mathematics word problems	Fifth grade	Mathematics word problems (practiced, near and far transfer, hard to visualize)	Draw group higher on practiced, near transfer; trend favoring drawing group on far transfer; no advantage on hard to visualize	Yes
Van Meter (2001)	Read; draw, draw with an illustration, draw and answer questions to prompt illustration comparison, and nondrawing control	Biology text	Fifth and sixth grade	Free recall; multiple-choice (recognition); accuracy; self-monitoring events (think alouds)	Most supported drawing group had most accurate drawings, free recall higher than control group; self-monitoring increased with drawing and support	Yes
Van Meter *et al.* (in press)	Read; draw, draw with an illustration, draw and answer questions to prompt illustration comparison, and written answers to prompt illustration-text comparison	Biology text	Fourth and sixth grade	Problem solving; multiple-choice (recognition)	Sixth grade supported drawing group had higher problem solving scores than control group	Yes

relations. In this study, second, fourth, and sixth grade students read a text about aliens that was organized into class-inclusion hierarchical relationships. One passage, for example, described imps, a type of imaginary space creature. The text explained that all imps have green skin, one eye, can fly, and have no hair. Additionally, there are two subclasses of imps—those with two horns and no freckles and those with four horns and freckles. The two subclasses, plain and spotted imps, were further subdivided into four specific classes. Given the option of drawing, writing, or constructing a diagram to represent text, nine second grade and six fourth grade participants choose to draw. With the text removed and drawings available as memory aids, positive correlations between drawing accuracy and performance on both identification and reasoning posttests were found. Given that Greene (1989) permitted participants to use the drawn representation at the time of the posttest, these positive correlations are not surprising.

More stringent tests of this hypothesis are provided by research in which participants constructed drawings during study but did not have them available when tested (e.g., Lesgold *et al.*, 1977; Linden and Wittrock, 1981). In a study by Lesgold *et al.* (1975, Exp. 1), for example, first grade participants listened to stories and their comprehension was assessed by free recall. Specifically, free recall was scored by counting the number of story propositions recalled. Half of the study participants were assigned to a drawing condition and half were assigned to a nondrawing control condition. After hearing the story, the drawing participants were given background scenes and figure cutouts with instructions to illustrate story events; the control participants colored simple figures. For participants in the drawing condition, the accuracy of drawings and scores on the free recall measure were positively correlated, in Exp. 1, however, the nondrawing control group recalled more story propositions overall than the drawing group recalled.

In a similar study, Lesgold *et al.* (1977) replicated these results. Specifically, Lesgold *et al.* (1977) reported a significant positive correlation between the accuracy of drawings and the number of story propositions recalled. In this study, however, drawings were examined to determine the relationship between what was specifically expressed in the drawing and what was specifically expressed in the free recalls. In drawings, each story proposition could be accurately represented, inaccurately represented, or omitted. Not surprisingly, accurately represented propositions had the highest probability of being accurately included in story recalls. Comparing propositions that were either inaccurately drawn or omitted, inaccurately represented propositions were more likely to be included in story recalls. Although Lesgold *et al.* (1977) used spoken rather than written language, these findings restrict the practitioner claim that drawing can be an easier expressional format than symbolic language (e.g., Hubbard, 1987; Karnowski, 1986). Apparently, some learners have difficulty accurately drawing even when content is understood (Lansing, 1981).

Taken together, the studies covered thus far support the hypothesis that the accuracy of representations predicts posttest performance. Uncovering the causal links of this conclusion, however, is another matter. One possibility is that learners who construct accurate depictions did not need this construction process in the first place. That is, a learner may accurately depict to-be-learned content because the text itself was easily understood. If true, text comprehension would predict both drawing accuracy and posttest performance. On the other hand, drawing construction may act as a learning strategy and mediate the relationship between text comprehension and posttest performance. If so, the process of drawing aids comprehension and, consequently, improves test performance.

An experimental test of these competing hypotheses is found in a study by Van Meter (2001). In this study, fifth and sixth grade participants read to learn about the central nervous system. Experimental participants constructed drawings under three conditions of increasing support. Support was in the form of provided illustrations and was designed to facilitate accurate drawing. Participants in the most supported condition were instructed to make drawings to represent text content during reading. These participants inspected provided illustrations after drawing, answered prompting questions that directed comparison of drawings and illustrations, and modified their drawings accordingly. In the next most supported condition, participants drew, inspected provided illustrations, and modified drawings, but were not provided with comparison prompting questions. These two supported groups were compared to a drawing group with no provided illustrations (i.e., no support) and a nondrawing control group with provided illustrations. Across the three drawing groups, participants in the most supported condition obtained the highest drawing accuracy scores. Importantly, participants in this condition were the only ones who scored higher on a free recall posttest than nondrawing control participants scored. Thus, in this study, experimental manipulations facilitated accuracy which, in turn, increased knowledge gain.

In summary, it is likely that, when content is easy and meaning is transparent, accurate drawings are a direct product of accurate comprehension. With more challenging materials, however, drawing may facilitate comprehension and learning.

Connecting With Recommended Classroom Practices. The conclusion that drawing accuracy is related to learning outcomes should be translated in the applied literature. We did not find a single applied article that even mentioned the role of drawing accuracy. The empirical literature is clear, however. Lesgold *et al.* (1975, 1977) and Van Meter (2001) demonstrate the importance of drawing accuracy when designing classroom implementations that use drawing as a comprehension or learning strategy.

Support is Necessary for Effective Drawing Strategy Use

As documented in the empirical and applied literature, learners have used the drawing strategy under a range of conditions. One way to identify these conditions is with respect to the supports provided in the experimental context. On one end of a support continuum, learners are provided no more support than simply the instructions to construct a drawing (e.g., Rasco *et al.*, 1975). Scattered across the continuum are a number of different ways in which drawing has been supported or constrained. For example, Alesandrini (1981) manipulated instructions to direct learners' attention to either individual structures within a scientific system or to how these structures were connected. Hall *et al.* (1997) supported drawing participants by including explicit instructions on what should be drawn. As another example, Lesgold *et al.* (1975, Exp. 2) provided figure cutouts and backgrounds that first grade students manipulated and combined to create drawings of story events.

To advance the hypothesis that support is necessary when students use drawing to learn complex materials, studies that permit comparisons of learner-generated drawing under both supported and unsupported conditions are necessary. These studies are reviewed in this section. The findings from this set of work are consistent with the conclusion that support is necessary for effective use of the drawing strategy.

A series of studies by Lesgold and colleagues (Lesgold *et al.*, 1975, 1977) permits comparison of increasing levels of support. In each of these experiments, first grade participants listened to stories and comprehension was measured by free recall. Half of the participants in each experiment were assigned to a drawing condition and half were assigned to a control condition. Control participants completed an interpolated coloring task. Drawing participants were provided background scenes and cutout figures to represent story events. In this case, selection of accurate figures and scenes, and manipulation of these provided elements constituted the drawing strategy.

In the study by Lesgold *et al.* (1975, Exp. 1), irrelevant distractor cutouts and scenes were included. Results showed that the drawing group had no advantage over the nondrawing control group on a free recall of stories. However, after noting the correlation between drawing accuracy and recall in Exp. 1, Lesgold *et al.* (1975, Exp. 2) increased the provided support by removing distractor elements. Thus, drawing required only that participants arrange figure cutouts in relation to one another and on the appropriate background. In this second experiment, drawing participants correctly recalled more story propositions than did control participants.

Using this same methodology, Lesgold *et al.* (1977) demonstrated that the benefits of this construction process were sustained even when stories were increased in complexity and length. Thus, when first grade participants attempted to construct representations in the presence of distracting manipulatives, the drawing intervention did not improve story recall relative to no intervention. However, when the drawing support was increased by presenting only accurate manipulatives to choose from, the strategy did improve recall.

Van Meter (2001) came to the same conclusion as Lesgold and colleagues—supported drawing participants acquire more knowledge from text than unsupported drawing and control participants. Unlike Lesgold *et al.* (1975), however, Van Meter varied support across drawing conditions in the same experiment and analyzed participants' think alouds to uncover causal links among drawing, support, and comprehension processes. As described in the previous section, fifth and sixth grade students who participated in this study read a two-page text about the central nervous system. Four groups were compared: two experimental groups, in which drawing was supported, one experimental group, in which participants drew without support, and a nondrawing control group. In the first support condition, participants were provided illustrations to inspect; in the most supported condition, these provided illustrations were followed by a set of questions directing participants to compare illustrations to drawings. In both support conditions, illustrations were hidden until after drawings were constructed although participants were permitted to revise drawings following illustration inspection. Results showed that learners in the most supported condition scored higher on a free recall measure than did nondrawing learners. Thus, the results of Van Meter support the hypothesis that support is necessary for drawing to improve learning from content area text.

The verbal protocols collected by Van Meter (2001) provide a window on both the processes that underpin the drawing strategy and the reasons why support may be necessary. These protocols were coded for evidence of self-monitoring events; events were operationalized as behavior indicating that a comprehension error was detected or fix-up efforts were engaged (Palinscar and Brown, 1984; Paris and Myers, 1981). Participants in all drawing conditions engaged in more self-monitoring events relative to nondrawing control participants. That is, students who constructed drawings evidenced greater awareness of their comprehension. These differences were quite substantial; unsupported drawing participants engaged in four times as many self-monitoring events as did nondrawing control participants. The hypothesis that learners require support to use drawing effectively is most directly addressed, however, by comparing the self-monitoring of participants in supported and unsupported drawing conditions. Van Meter reported that participants in the most supported condition engaged in more self-monitoring events than participants who drew without support. Thus, an important finding is that participants who drew with support detected and attempted to correct more comprehension errors than either participants who drew without support or those who did not use the strategy at all. These findings, in conjunction with posttest results, lead Van Meter to conclude that although drawing itself may prompt learners to detect more errors in comprehension, this strategy alone does not provide adequate support to correct these errors.

In a partial replication of Van Meter (2001), Van Meter *et al.* (in press) duplicated the beneficial effects of support. In this study, the same supported drawing groups were compared to a more stringent nondrawing control group. Participants in the control group wrote answers to provided questions that required participants to locate information in first the verbal text and then in the illustration. These questions directed comparison of the text and provided illustrations. Fourth and sixth grade participants read a text describing the structures and functions of bird wings. The posttest assessment included a conceptual transfer test. Despite the increased activity on the part of control participants, sixth grade participants in both supported drawing groups scored higher on the problem solving assessment than control group participants scored. Conversely, fourth grade drawing participants did not score higher relative to nondrawing control participants regardless of the level of support. Although the performance of the fourth grade participants warrants further investigation, on balance, the findings from both Van Meter studies (Van Meter, 2001; Van Meter *et al.*, in press) support the hypothesis that providing support increases the effectiveness of learning-generated drawing.

The third piece of evidence upholding the support hypothesis comes from the work of Alesandrini (1981). This study contrasted writing and drawing strategies as college students read to learn about electrochemistry concepts and the structural components of a cell battery. Support was provided in the form of instructions that directed participants' attention. Participants in the three writing conditions wrote paraphrase statements under instructions to attend to holistic (systems level) aspects of the representation, analytic (individual components) aspects of the representation, or with no specific instructions. Participants in the three drawing conditions made drawings under instructions to attend to holistic (systems level) aspects of the representation, analytic (individual components) aspects of the representation, or with no specific instructions. A read twice condition was included as a no treatment control.

When the read twice control group was excluded from the analysis, a 2 (strategy) × 3 (instructions) ANOVA revealed a main effect of strategy. Drawing participants scored higher on a multiple-choice posttest than did writing participants. When the read twice control group was added to the analysis, participants in all drawing groups obtained higher scores than did control group participants. To examine the hypothesis that provided support effects drawing efficacy, the most telling comparisons are those that contrast the three drawing groups. This contrast shows that drawing with holistic instructions led to greater knowledge gains than drawing with analytic instructions or no instructions. On the whole, this study demonstrates that learner-generated drawing is a strategy that can facilitate learning of complex, scientific material. The performance of participants in the draw-holistic condition further indicates that supportive instructions add to the benefit of drawing.

Connecting with Recommended Classroom Practice. The empirical evidence indicates that when drawing is used to facilitate the acquisition of knowledge, the support provided should be considered. Unfortunately, there is no attention to this issue in the applied literature. Johnson (1988), for example, recommends drawing as a means to help high school students learn grammar rules. Nowhere in the Johnson article, however, is there any mention of the drawing support learners may need. The same is true of McConnell's (1993) recommendations with respect to learning from expository text, Constantino's (1986) recommendations for learning story structure, and Stein and Power's (1996) ideas about how drawing can facilitate learning in science. Britton and Wandersee (1997) can be credited with having included support in their practice of using drawing to learn complex science concepts. Disappointingly, however, the potential importance of this support or how it might be used was never addressed. In summary, we conclude that the practical literature that informs classroom practice is silent on the role of support.

The Benefits of Drawing Construction Are Revealed on Higher-Order Assessments

Educational researchers should consider the match between the intervention tested and the posttests likely to be sensitive to the intervention (Kintsch, 1994; Levin and Mayer, 1993). Although some interventions may be effective at increasing learners' knowledge and memory for facts, others encourage learners' to construct more sophisticated mental models of to-be-learned content. With the latter interventions, posttests measuring only factual recognition and recall may not be sensitive to learners' actual knowledge gains. This appears to be what has happened with respect to the research on learner-generated drawing. This body of research is replete with studies employing poorly matched posttests that likely mask the effects of drawing. This can be demonstrated by sorting drawing studies into two piles: one pile for studies reporting significant, positive effects of learner-generated drawing and a second for studies in which these effects were not found. A factor that distinguishes the two piles is the nature of the posttests used to assess learning outcomes; favorable studies used higher-level knowledge assessments whereas studies with less favorable outcomes tended to use lower-level knowledge assessments.

Van Meter and colleagues (Van Meter, 2001; Van Meter *et al.*, in press) directly tested the hypothesis that the benefits of drawing would be revealed on higher-, but not lower, level assessments. Van Meter (2001) used both a free recall and a multiple-choice recognition posttest. Because the technique used for coding free recalls measured participants' knowledge of systems-level connections within the central nervous system, this posttest was classified as a higher-order knowledge assessment. Using this scoring technique, fifth and sixth grade students who constructed drawings with support recalled more text ideas than nondrawing controls recalled. Conversely, there were no advantages for any drawing groups on the recognition test.

Similar posttest comparisons were included in the study by Van Meter *et al.* (in press). Fourth and sixth grade participants read a two-page text describing the system of a bird's wing. Although the drawing conditions replicated those of Van Meter (2001), nondrawing controls in this study used a verbal strategy. Outcomes were assessed on a multiple-choice fact recognition test and a two-item conceptual transfer problem solving task. One problem solving item described a bird's trouble with flight and required participants to identify the malfunctioning structure and explain why this structure would cause the described problem. The second problem solving question worked in reverse—given a malfunctioning structure, participants had to describe how flight would be affected. Sixth grade students in both supported drawing conditions scored higher on this problem solving posttest than nondrawing control participants scored. Also consistent with the findings of Van Meter (2001), no benefits for learner-generated drawing were revealed on the assessment of factual recognition.

Learner-generated drawing has also been used as a strategy in mathematical learning and performance. Once again, the nature of the assessments consistently affects results. When learners have used drawing to aid problem solving, learners who draw have an advantage over learners who do not draw (e.g., van Essen and Hamaker, 1990, Exp. 2). When mathematical knowledge has been assessed through low-level verbally-based posttests, however, learners who draw do not score higher than learners who do not draw (e.g., Rasco *et al.*, 1975).

In a study by de Bock *et al.* (1998, Exp. 2), for example, 15- and 16-year-old participants, instructed on how to draw to represent problems of proportionality, were compared to participants in a nondrawing condition and those in a provided-drawing comparison condition. Over the course of two training sessions, each drawing participant practiced making drawings of word problems and explaining these to the experimenter. An experimenter-constructed drawing was then shown and discussed with the participant. On the assessment, participants from all conditions completed a problem solving posttest. No condition effects were found on this posttest. DeBock *et al.*, however, discovered that even drawing-trained participants failed to make drawings for a number of the math word problems. Subsequently, within the drawing condition, problems were reclassified as those for which drawings were and were not constructed. A chi-square analysis revealed there was a higher probability of correctly solving a problem when a drawing was constructed than when one was not constructed. Nondrawn problems had a higher probability of being incorrectly answered. Accordingly, de Bock *et al.* concluded that drawing construction could facilitate mathematical problem solving.

van Essen and Hamaker (1990, Exp. 2) also found that drawing facilitates mathematical problem solving. Fifth grade participants in this study were trained to use drawing as a strategy for solving word problems. Outcomes were assessed on a test that included previously practiced, near transfer, and far transfer word problems. Drawing-trained participants scored higher than untrained participants on both practiced and near transfer problems; on far transfer problems, a strong trend favored drawing participants. Unlike participants in the de Bock *et al.* (1988) study, participants in the van Essen and Hamaker (1990, Exp. 2) study used the drawing strategy to solve the tested math problems.

Based on the results of van Essen and Hamaker (1990, Exp. 2) and de Bock *et al.* (1988), we conclude that drawing is an effective strategy for mathematical problem solving. The importance of this problem solving measure is emphasized when these two studies are contrasted with a study conducted by Rasco *et al.* (1975). In this study, fourth and fifth grade participants read to learn the mathematical concepts of intersection and empty sets. The posttest was a 20-item multiple-choice test assessing verbal information rather than problem solving or knowledge application. For the test of verbal information, no benefits of drawing were found. Thus, discrepancies in the results obtained by Rasco *et al.* (1975) in comparison to those reported by van Essen and Hamaker (1990, Exp. 2) and de Bock *et al.* (1988) could be accounted for by the different types of assessments used.

A series of studies by Lansing (1981, 1984) provides further evidence that the benefits of drawing are revealed on higher-level assessments. Lansing (1981) used an innovative assessment to test the benefits of learner-generated drawing with kindergarten children. Experimental participants were shown a two-dimensional model as a line drawing. In three experimental conditions, participants were instructed to observe the model, trace it with a finger, or draw it. All experimental participants had six exposures to the model over a 3-week period. Control groups, who did not have repeated exposures, were included in the experiment. The assessment, identical at pretest, posttest, and delayed posttest, employed the same two-dimensional model and required participants to complete two tasks. First, all participants were asked to observe and then draw the model from memory. Second, participants completed a model recognition distractor task. On this distractor test, a single page showed five possible variations of the model with variations determined by removing or altering one of the elements (e.g., changing the number of dots in each model variation). No model example was identical to the target model and the task was to select the variation most closely resembling the target. A total of eight items were included on the distractor test.

Although the drawing group did better on the model drawing task, this assessment too closely resembles the drawing training conditions to provide a meaningful comparison. Furthermore, the task of replicating an observed model does not tap higher-order cognitive process. The distractor test, however, requires participants to transform their mental image of the studied model to select the most similar option. Given developmental trends with respect to generating and manipulating internal images (Pressley and Van Meter, 1993), this distractor test is considered a measure of higher-order cognitive processing. On this assessment, drawing groups had higher pretest to posttest gain scores than nondrawing groups. This pattern held for both immediate and delayed posttests. Lansing (1981) concludes that drawing, in comparison to observation and ringer tracing, "has a positive effect on the development of mental representations" (p. 21).

In 1984, Lansing published a continuation of this study. Although the same experimental conditions were not included, Lansing did use the same to-be-learned model and the learning assessments. Kindergarten children in three drawing conditions drew the model with a pencil for two sessions, or six sessions, or six sessions with directive instructions. These groups were compared to two other groups in which children drew with either large or small paintbrushes. Although the groups that used pencils for six sessions with and without instructions were the two highest scoring groups on the drawing test, no condition effects were found on the distractor test. Because Lansing (1984) intended this study to be a continuation of the 1981 study, however, no control or nondrawing comparison groups were included in 1984. A comparison of group means across these two studies, however, indicates that drawing participants in the second experiment had higher gain scores on the distractor test than those who did not draw in the first experiment.

Consistent with Lansing's (1981) conclusion, studies addressed thus far support the contention that the effects of learner-generated drawing are best assessed by higher-level posttests. There are exceptions to this trend, however, and these exceptions warrant attention. In one of these exception studies, Hall *et al.* (1997) had college students read modified versions of Mayer's text on air pumps (e.g., Mayer and Anderson, 1991; Mayer and Sims, 1994). In three experimental conditions, participants were either provided the text and illustrations, provided only the text, or were provided the text and given instructions to draw. The posttest, also taken from Mayer's work, was a conceptual transfer test requiring the application of text knowledge. Although this test taps higher-order knowledge, drawing participants did not obtain higher scores than those who inspected illustrations but did not draw. On the surface, the contradictions from this study are difficult to assimilate with the hypothesis that drawing benefits are revealed on higher-order posttests. A deeper look at task instructions and drawing support, however, reveals what may be an important difference in Hall *et al.*'s implementation of the drawing strategy.

All participants in the Hall *et al.* (1997) study received the same general task instructions and read a text with an identical body. For drawing participants, however, general instructions were followed by a single paragraph describing the components of the pump and explicitly indicating what should be drawn; e.g., "... draw a cylinder which is about 2 in. [5.08 cm] long ...," "Then draw a small rod (about 1/8 in.... wide) ...," etc. (p. 678). This paragraph was followed by the seven paragraphs making up the body of the text; the same seven paragraphs read in all conditions of the study. Throughout the remainder of the experimental task, no additional references were made to drawing. Instead, drawing participants were instructed to "imagine" what various aspects of the pump might look like. Thus, drawing participants were not directed to use the drawing strategy *while* learning the content nor were they encouraged to reinspect drawings while reading. Further, because the opening paragraph told participants what to draw and exactly how to draw it, the drawing methods used by Hall *et al.* vary substantially from other studies. Participants in studies by de Bock *et al.* (1998), Alesandrini (1981), and Van Meter (2001) had to determine which elements should be selected, how these elements should be represented, and how they should be organized with respect to one another. Participants in the Hall *et al.* study, by contrast, were explicitly and exhaustively provided with this information. Consequently, it is unlikely that the methods employed by Hall *et al.* encouraged higher-level comprehension processes of the type uncovered in Van Meter (2001). Therefore, it should not be surprising that drawing participants did not have higher transfer scores relative to illustration-provided participants.

A second study, that of Tirre *et al.* (1979), is also inconsistent with the assessment hypothesis though only superficially so. College students read short, expository texts that presented three different target objects. Participants in the drawing condition had to make a drawing to identify the concept that related the target objects; participants in the writing condition had to write sentences explaining the concept that related the target objects. These two groups were compared to a read only control group. Texts covering both concrete and abstract concepts were included to test the hypothesis that drawing would facilitate learning of concrete concepts, but writing would facilitate learning of abstract concepts. The result was a 2 (content type) $\times$ 3 (strategy) design. The posttest, arguably a measure of higher-order learning, assessed knowledge of relationships among targeted objects. Across both concrete and abstract texts, participants employing the writing strategy scored higher than did drawing participants. Notably, drawing participants scored higher on the posttest than did control participants.

Is this case a failure for the learner-generated drawing strategy? Although we believe this study points out a limitation of the strategy, as does the study by Hall *et al.* (1997), we do not consider the study by Tirre *et al.* (1979) to be a reasonable test of the strategy. In Tirre *et al.*'s study, the problem lies in the poor match between the strategy and the task. Consider, for example, the task given to drawing participants in one of the concrete passages, a passage about beavers, muskrats, and round-tailed water rats. Participants had to identify the concept that related the three targets and draw a picture that incorporated this comparison. For this text, the correct relationship is that although the tails of these animals are of different shapes, they are all used for the same purpose.

What would the right drawing look like in this case? We are hard pressed to think of how one might construct a single drawing that would reveal three different appearances. Conversely, a participant might not take the "single" drawing instruction literally and may draw three different animal tails. This process however, would not help participants focus on the comparison of the three targets but would direct attention to each animal in succession. As Alesandrini (1981) found, drawing is most effective when the strategy directs learners to consider objects in relation to one another, not separately. Finally, it is worth noting that this example comes from one of the *concrete* passages. Abstract passages placed drawing participants at an even greater disadvantage. As an example, consider reading an archeological text on Roman Literature, Greek Literature, and the Bible. It is not clear what a learner could draw to illustrate the concept that each of these writings stimulated interest in archeology.

A final piece of evidence supporting the assessment hypothesis comes from contrasting the studies of Alesandrini (1981) and Snowman and Cunningham (1975). On the surface, these studies are similar. In both, college students read expository text, writing and drawing were compared, and factual knowledge was assessed on a multiple-choice posttest. In Snowman and Cunningham's study (1975), participants read social studies text and either wrote or drew in response to adjunct questions. In Alesandrini's study (1981), participants read science text and wrote or drew under holistic, analytic, or no instructions. Despite the similarities in methods, the results of these two studies are quite different. Snowman and Cunningham found that writing proved more effective than drawing; Alesandrini found that drawing was more effective than writing.

The results of both studies can be accounted for by the hypothesis that drawing is best matched with higher-level posttests. Alesandrini's (1981) multiple-choice posttest included factual recognition items, but the majority of test items assessed higher-level comprehension or application of ideas. In contrast, Snowman and Cunningham's (1975) multiple-choice posttest included only factual recognition items.

Connecting with Recommended Classroom Practice. The hypothesis that higher-, but not lower-, order assessments are sensitive to the effects of drawing is upheld by the empirical literature. Again, however, empirical and applied efforts are unrelated. Although several authors recommend drawing as an effective classroom learning strategy, none of the applied articles explicitly addressed the outcome assessments. In fairness, there is an implied awareness running throughout the applied literature. Applied articles credit drawing for promoting understanding (e.g., Johnson, 1988), directing students to think (e.g., Stein and Power, 1996), revealing misconceptions (e.g., Britton and Wandersee, 1997), and guiding the integration of ideas across text (e.g., Rich and Blake, 1994). These drawing attributes suggest a belief that drawing should be used for more than memorization tasks.

Summary

The review of empirical literature was organized around three drawing hypotheses. The discussion of each hypothesis ended with the conclusion that empirical findings are not being accommodated in the applied literature. To be equitable, the research community has also ignored the issues raised by those concerned about classroom implementation. We found no research program, for example, tied to the practical implications described in the previous section of this article. No researchers are asking if drawing can improve observational processes, support the writing process, or improve learner affect. In short, both communities are pursuing independent and, at times, contradictory, paths with respect to learner-generated drawing.

In closing this section, it seems that all three of the hypotheses discussed are supported by research. On the other hand, this review makes clear how little is known about drawing. The hypotheses presented to this point are just that—assertions that require further testing before specific recommendations are warranted. The lack of available, systematic research leaves only a limited number of studies with widely varying methodologies for consideration. Consequently, the synthesis of this literature contains gaps and permits only tentative conclusions.

At the outset of this article, we communicated our intent to spark additional drawing research by pointing out the discrepancies between research and practice. We also indicated our belief that a theoretical framework is necessary to achieve the goal of a systematic research program. In the following section, a framework for understanding learner-generated drawing is proposed. Interwoven with the explanation of the framework are past findings and future research questions.

LEARNER-GENERATED DRAWING: A THEORETICAL FRAMEWORK

The theoretical framework proposed here is the Generative Theory of Drawing Construction. Not a new theory, this perspective is founded in Mayer's Generative Theory of Textbook Design (e.g., Mayer *et al.*, 1995; Mayer and Gallini, 1990). Originally, proposed to explain the processes underlying learning from illustrated text, we have adopted Mayer's proposal to hypothesize about the processes underlying drawing construction. In order to more fully understand this framework as it is applied to drawing, a brief explanation of Mayer's framework is provided below. In this description, the reader should recall how drawing was defined at the outset of this article. Specifically, when drawing, a learner must select to-be-represented elements and organize them into a symbolic verbal representation. This representation subsequently provides the foundation for referencing, or constructing nonverbal representational units and organizing them into a nonverbal representation. The two internal representations are integrated by mapping corresponding elements onto one another.

The Generative Theory of Textbook Design

Proposed to account for how readers process illustrations in conjunction with text, the Generative Theory of Textbook Design credits both Wittrock's Generative Learning (1974, 1989) and Paivio's Dual-Code (1986; Clark and Paivio, 1991) theories. Commensurate with these two theories, the Generative Theory of Textbook Design proposes that readers construct an internal verbal representation of the written words and an internal nonverbal representation of illustrations when reading illustrated text. Constructed and organized separately, these two internal representations are integrated while referential connections are generated to join the two. The integrated representation is equivalent to the learner's mental model of to-be-learned content (Mayer, 1993; Mayer and Sims, 1994).

Three cognitive processes—selection, organization, and integration—lead to the construction of the mental model. In selection, the reader identifies key elements present in each of the external, verbal and visual, representations. Using selected elements as the foundation, learners independently organize internal representations to build a coherent representation of both the text and the illustrations. This organization takes place as associative connections between internal concepts are either activated (from prior knowledge) or generated. The third process, integration, is the process by which mental models are constructed. Integration requires generation of referential connections to link internal verbal and nonverbal representations. As a result, the learner stores a mental model of target content in which both verbal and nonverbal representations are integrated. It is the mental model that is credited with enhancing learners' problem solving abilities and conceptual understanding (e.g., Mayer and Gallini, 1990; Mayer and Sims, 1994).

The following section explains how this framework can be applied to understand the processes underlying drawing construction. In addition, each of the three hypotheses proposed in the previous section are addressed.

The Generative Theory of Drawing Construction

Selection is altered when applied to learner-generated drawing. Consider that when both text and illustrations are provided, key elements are selected from both depictions. When drawing without available illustrations, however, selection cannot be applied to a provided nonverbal representation. Instead, elements can only be selected from the verbal representation. Accordingly, the selection of elements for the internal, nonverbal representation is solely determined by the verbal representation.

When both text and illustrations are provided, these two representations likely constrain the selection of elements from one another. Thus, a student reading about the system of a bird's wing identifies feather sheath, keratin, and barbs as key elements from the text. The selection of these elements guides the selection of corresponding elements from the illustration; the learner inspects the illustration to locate each of these components. Inspection of the illustration may, in turn, cause the learner to notice something important—the barbs overlap one another—which leads to closer inspection of the text and, possibly, the selection of additional elements, in this back and forth consideration, the two internal representations act as mutual constraints during construction of the mental model. This idea is consistent with Schmalhofer's (1998) explanation of the constraint satisfaction process in the construction of situational models. Specifically, using a connectionist framework, Schmalhofer explains that representational units that fit together well obtain high enough activation levels to remain part of the representation that is stored in long-term memory. Units with lower levels of activation, those that do not fit well, are disconnected from the stored network representation. Applied to drawing, constraint satisfaction means that verbal and nonverbal representational units that fit well together will be retained in the stored representation of to-be-learned content. For the learner drawing without the aid of provided illustrations, no such constraint is available.

Organization during drawing is also impacted by the representations and constraints available. When drawing, the internal verbal elements are organized into a coherent representation. This representation then serves as the foundation for constructing the internal nonverbal representation. This means that the verbal representation plays an important role in both the selection of elements to be included in the nonverbal representation and the organization of a coherent internal nonverbal representation. Specifically, the organization of the verbal representation must be used to guide the organization of the nonverbal representation during the constructive process. When learning about a bird's wing, for example, once the learner has selected the elements keratin and feather sheath for representation, the internal verbal representation determines how these two imagens should be organized in relation to one another. This process is not entirely linear. Attempts at constructing the nonverbal representation can send learners back to either the verbal representation or the text as difficulties building the internal image are encountered (Van Meter, 2001).

In this description, drawing requires that existing referential connections be used to activate relevant imagens from prior knowledge. The learner, for instance, is likely to have a representation of a feather sheath already stored in the nonverbal knowledge base. Newly encountered concepts, on the other hand, require that imagens be constructed solely on the basis of provided verbal descriptions. The reader may have to build an image of barbs, for example, simply from the description provided. As a result, it is predicted that a learner's prior knowledge acts as a critical, and as yet unexplored, support when using the learner-generated drawing strategy. Further research is needed to consider exactly how this prior knowledge may function as a support when learners draw.

Although we have seen that both selection and organization processes differ when learners are drawing, in the model proposed here, integration is the step most extensively changed when comparing learning from illustrated text to learner-generated drawing. Specifically, when drawing, the process of organizing nonverbal representations is not distinct from the processes of integrating verbal and nonverbal representations. Instead, as the organized verbal representation is used to construct the nonverbal representation, these two representations are necessarily integrated.

This aspect of integration highlights another difference between the inspection of provided illustrations and the construction of drawings, a difference suggesting that drawing may have a learning advantage over the provision of illustrations. Here, we are referring to the number of troubling instances in which learners fail to inspect illustrations (Hegarty *et al.*, 1991) and to demonstrations that illustrations and other representations may not improve learning even when experimental manipulations make the integration of text and illustrations likely (e.g., Iding, 1997; Scanlon, 1998; Scevak *et al.*, 1993; Scevak and Moore, 1998; Tabachneck-Schiif and Simon, 1998). Collectively, the literature on this issue leads to the conclusion that mere reliance on cooccurrence of multiple representations may be insufficient for the integration of these knowledge representations (de Jong *et al.*, 1998). With a drawing strategy however, integration itself is forced as the verbal representation is the foundation for the nonverbal representation.

We believe it is this integration that underlies the effect of provided support and the positive relationship between drawing accuracy and knowledge gains. With respect to support, for example, consider that mental models are built as concepts from verbal representations, are replicated in nonverbal representations, and these overlapping elements are mapped onto one another (de Jong *et al.*, 1998). Where the two representations actually contradict one another, both the text and illustrations are available to address this inconsistency. Thus, one representation can be used to resolve questions about the accuracy of the other.

For the learner drawing without support, however, no such backup is available. Without this auxiliary representation, not only may the learner fail to detect inaccuracies in understanding, even detected ones may go uncorrected (Van Meter, 2001). These uncorrected comprehension errors are passed on to the nonverbal representation and, ultimately, to the mental model responsible for problem solving and higher-order thinking. Drawing research that has uncovered the relationship between drawing accuracy and posttest scores (e.g. Greene, 1989; Lesgold *et al.*, 1975) is likely identifying this phenomenon.

When drawing support is provided, however, this support acts as a constraint on the construction of the nonverbal representation. First, supports may aid reading comprehension, thereby insuring that constructed verbal representations are accurate. Because the nonverbal representation is built from it, the accuracy of the verbal representation affects the potential accuracy of the nonverbal representation. Alternatively, support may guide the construction of drawings themselves and, therefore, serve a crucial supplementary role. Experimental instructions to attend to each structure's fit and role within a system, for example, may help the learner attend to and figure out critical features of a system (Alesandrini, 1981).

Given the variety of supports that have been empirically tested, it is difficult to credit specific processes beyond these generalities. It is likely, however, that support acts to do three things: (1) constrain the construction of drawings (e.g., Lesgold *et al.*, 1975); (2) check the accuracy of constructed drawings (e.g., Van Meter, 2001); (3) and/or direct learners' attention to key elements and their relationships in the text (Alesandrini, 1981). Clearly, more research is needed to determine if these three processes truly are the factors that determine the effect of support and if each of these plays an equally important role. One might ask, for instance, which is more effective—the use of supports that direct and constrain the learner in constructing an accurate drawing or supports that improve the learner's ability to detect and correct errors in constructed drawings?

Research is also needed to consider the potential role of prior knowledge. A learner's prior knowledge may both guide and constrain the construction process, thereby acting as a support. Recall the earlier example of the hypothetical learner constructing a nonverbal representation of both a feather sheath and barbs. The learner had a stored imagen of feather sheath that could be activated and used in service of drawing construction. The barbs, on the other hand, had to be built solely on the basis of the verbal description. Because there is not a one-to-one relationship between logogens and imagens (Paivio, 1986), it is possible for a variety of nonverbal representations to be created from the verbal description that barbs are hooks and catches that lock feathers together. Subsequently, it is likely that the nonverbal representation of feather sheath is accurate whereas the nonverbal representation of barbs may be either entirely or partially inaccurate. Background knowledge, therefore, can serve an important support function during drawing. Furthermore, it is likely that the importance of prior knowledge is inversely related to the degree of external support provided: As the degree of provided support decreases, the need for prior knowledge increases.

The integration process may also explain why drawing benefits are revealed on higher-order assessments. Integration is the process underlying mental model construction and, because these models do not retain the verbatim textbase, it is not surprising that drawing benefits are not revealed on lower-order posttests. On the other hand, learners who construct mental models have an advantage on assessments of problem solving, application, and higher-level comprehension (McNamara *et al.*, 1991). As with questions regarding the role of support, research is needed to identify the specific tasks and outcomes for which drawing is most appropriate.

CONCLUSION

Applying the Principles of Strategy Instruction

The choice to label learner-generated drawing as a strategy was explained at the outset of this article. It was explained that drawing is a strategy because it is consistent with several dimensions along which strategies are defined. There is one characteristic of strategies not yet discussed—the potential for the strategic process to be taught, practiced, and improved. Unfortunately, in the research literature, drawing has not been treated as a teachable strategy. In both the applied and empirical literature, few instances are found in which drawing was either taught or practiced (e.g., Lansing, 1981, 1984; Van Essen and Hamaker, 1990). Instead, drawing has typically been treated like an adjunct aid. In this sense, drawing is comparable to verbally-based adjuncts that also require a learner-generated response. Examples of these include adjunct questions (e.g., Hamaker, 1986; Holliday and McGuire, 1992) and matrix notes (Kiewra *et al.*, 1989, 1991).

Drawing has more in common with these adjuncts than simply a lack of strategy-like instruction. Like learner-generated drawing, research has demonstrated that the effectiveness of these adjuncts is related to the provision of external support (e.g., Kiewra *et al.*, 1995) and that these adjuncts influence learners' self-monitoring processes (Kulhavy *et al.*, 1976). With respect to matrix notes, for example, Kiewra *et al.* (1995) found that the number of cells included in a provided matrix affected not only the quantity of notes taken but also posttest performance. The completed cells likely supported learners by indicating both the topics and subtopics that should be addressed in notes. Similarly, Katayama and Robinson (2000) concluded that in comparison to complete or skeletal matrix notes, partially completed matrix notes are the most effective adjunct aids.

Another interesting parallel between learner-generated drawing and adjunct aids is illustrated by Kulhavy *et al.* (1976). Recall Van Meter's (2001) finding that drawing participants engaged in more self-monitoring events relative to nondrawing participants. Recall further that as drawing support increased, the number of detected and corrected comprehension errors also increased. These findings should be interpreted in the light of Kulhavy *et al.*'s (1976) research. They had participants read and answer adjunct questions. Participants gave confidence ratings for each answer indicating how certain they were of answers. Feedback was given, in a correct/incorrect form, and participants' responses to feedback were recorded. When feedback that a response was incorrect followed high confidence, participants reinspected the text. On the other hand, when feedback that a response was incorrect followed low confidence, participants did not reinspect the text. Kulhavy *et al.* (1976) conclude that when a learner is aware that he does not understand and feedback provides only yes/no information, the learner does not attempt to correct the error. In short, telling a learner he does not understand, when he already knows he does not understand, provides no information that can be used to improve performance. Without additional support, the learning process is stymied.

This, of course, is the same conclusion drawn from Van Meter (2001) and other studies in which supported and unsupported drawing conditions could be compared. Instructions to draw, if the learner does not know what or how to draw, might increase awareness of confusion but will do little to change the situation. It would seem, then, that Rothkopf's (1982) warning with respect to adjunct aids applies to drawing as well: simple insertion of this task element will not magically transform learner processing.

What we do not know, what we have not yet begun to study, is whether providing instruction on how to draw strategically improves learners' independent use of drawing. As students internalize the processes of drawing, for example, dependence on external forms of support may decrease. Following the principles of effective strategy instruction (e.g., Duffy, 2002; Rosenshine and Meister, 1997), one can imagine a line of research in which students are taught the procedural components of drawing, explicitly told the conditions in which this strategy could be used, and are provided reasonable practice and feedback. Although the task of teaching any strategy, especially one as complex as drawing, can be daunting, the potential payoff may prove well worth it.

Closing Remarks

Much remains to be done before learner-generated drawing is fully realized as a strategy to enhance the acquisition of knowledge. The potential value of this strategy is made apparent by the cognitive processes believed to underlie drawing construction. In the process of drawing, learners are directed to integrate this generated representation with the representation of provided material. The result is a mental model of the concept that is more flexible than isolated representations can afford (Mayer, 1989; van Someren *et al.*, 1998).

Several unanswered questions have been brought to light in this article. Questions about the conditions under which drawing is effective, appropriate posttests, and reasonable applications have been raised. By embedding specific hypotheses within a broader theoretical framework, systematic research around a common set of questions is possible. At least as a starting point, this research agenda should address the nature of effective support systems, the role of prior knowledge, and the tasks and assessments that are best matched to drawing. In addition, research in which the principles of strategy instruction are applied to drawing should also be pursued. If this research is combined in a systematic effort, the potential of drawing as a strategy to improve learning and problem solving will be realized.

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