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Toward a theory of learner-generated drawings: The generative theory of drawing construction

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Learner-generated drawing as a strategy for learning from content area text

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Abstract

Learner-generated drawing is a strategy that can improve learning from expository text. In this paper, a model of drawing construction is proposed and the experimental design tests hypotheses derived from this model. Fourth and sixth grade participants used drawing under three experimental conditions with two conditions including varying degrees of support. On a problem solving posttest, both supported drawing groups scored higher than the non-drawing Control group. Although the grade by condition interaction was not significant, there was a strong trend in this direction. When sixth grade participants were considered independently, participants in the most supported drawing condition also obtained higher problem solving scores than those who drew without support. There were no significant condition effects for fourth grade nor were there any significant effects on a multiple-choice recognition posttest. Results were consistent with hypotheses and are discussed in light of the proposed theoretical framework.

Keywords: Drawing; Learning strategy; Content area text; Reading; Science; Assessment; Problem solving

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1. Introduction

Learner-generated drawing is a strategy in which readers construct drawings to represent to-be-learned content in order to improve learning from content area text (Alesandrini, 1981; Hall, Bailey, & Tillman, 1997). Empirical evidence that drawing improves learning on higher- but not lower-order assessments is consistent with theoretical assumptions that drawing leads to the construction of a mental model (Van Meter & Garner, in press). Although drawing has been studied sporadically, a lack of systematic investigation has prevented a complete understanding of the conditions under which this strategy improves learning. This article reports an experimental test of drawing that is grounded in a proposed model of the drawing process. Specifically, the design of this study was guided by hypotheses about the nature of the cognitive processes that underlie drawing construction, characteristics of acquired knowledge, and the type of posttest assessments likely to reveal strategy benefits. Before addressing these hypotheses specifically, however, it is necessary to define learner-generated drawing.

1.1. Learner-generated drawing

When used to support text learning, drawing is a strategy in which readers construct a pictorial representation of concepts described in text. Specific drawing methods have varied greatly across studies. Participants in a study by Alesandrini (1981), for example, made drawings of science concepts using only paper and pencil and instructions to draw. Lesgold, DeGood, and Levin (1977), by contrast, provided learners with cut-out figures and drawing involved organizing these into an accurate pictorial representation of story events. The common factor across studies, a factor that defines the drawing strategy, is the learner's construction of an external visual representation, or picture, of to-be-learned content.

The definition is further developed by both the requirement that learners maintain responsibility for the final appearance of drawings and the constraint that final drawings are representational (Van Meter & Garner, in press). By representational, we mean that learners make drawings which are intended to show how depicted objects actually look (Carney & Levin, 2002). This requirement excludes graphic constructions which are nonrepresentational such as flowcharts and concept maps. Furthermore, drawing is classified as a strategic process because drawing is goal-directed, improves knowledge organization, and can improve learning outcomes (Paris, Lipson, & Wixson, 1983).

In past drawing research, methodological variations have involved more than differences in specific drawing methods. Participants in these studies have ranged from first grade (e.g., Lesgold, Levin, Shimron, & Guttman, 1975) to college students (e.g., Snowman & Cunningham, 1975); to-be-learned content has included science topics (e.g., Van Meter, 2001), math word problems (van Essen & Hamaker, 1990), and social studies text (Dean & Kulhavy, 1981, Experiment 1). Outcome assessments have also varied with free recall (Kulhavy, Lee, & Caterino, 1985), comprehension (Alesandrini, 1981), and recognition (Rasco, Tennyson, & Boutwell, 1975, Experiment

3) posttests employed across studies. Because these variations have not been systematically studied, it is not surprising there is little consistency in the findings of these studies. Although Alesandrini (1981) and Dean and Kulhavy (1981, Experiment 1), for example, found that drawing improved learning from text, there were no drawing benefits in studies by Rasco et al. (1975) or Snowman and Cunningham (1975).

Van Meter (2001) addressed these inconsistencies by testing a series of hypotheses derived from the patterns across previous studies. First, Van Meter hypothesized that, when material is challenging, learners require some form of additional support to effectively use the drawing strategy. Further, Van Meter tested the assertions that drawing processes improve readers' on-line comprehension self-monitoring and that drawing improves performance on higher-order posttest assessments but does not improve performance on lower-order posttest assessments.

In the study by Van Meter (2001), fifth and sixth grade participants read about the central nervous system and completed both a multiple-choice recognition and a free recall posttest. Verbal protocols were collected as participants read the text and constructed drawings. All drawing participants read the two-page text and made two drawings to represent the concepts presented on each text page. Drawing methods involved providing participants with blank paper and a pencil and instructing participants to make a picture to show the important ideas in text. Three experimental drawing conditions tested the degree of provided support learners need to use drawing effectively. In the most supported condition, after each drawing was complete, participants inspected a provided illustration and answered a series of prompting questions that directed comparisons of provided and constructed drawings. A second support condition included the provided illustrations but not the prompting questions. These supported conditions were compared to an unsupported drawing condition in which participants were provided only the written text and blank paper for drawing. In a fourth condition, a non-drawing control condition, participants were provided both the text and the two illustrations but did not draw.

The hypothesis that drawing results in the acquisition of a mental model was tested by scoring free recalls to capture learners' systems-level understandings. The multiple-choice recognition posttest was included to test the hypothesis that drawing improves performance on assessments of higher-, but not lower-, order knowledge. The rationale underlying these assessment and scoring method choices was grounded in theories of knowledge representation. Specifically, elaborative, strategic activities such as drawing should lead to the construction of a mental model (Kintsch, 1994; McNamara, Miller, & Bransford, 1991). Although the mental model integrates prior knowledge, includes elaborative inferences, and supports flexible processing, this model does not retain the verbatim textbase. Thus, learners constructing mental models can be expected to perform better on higher-order assessments but are not necessarily expected to have an advantage on assessments of detail recognition.

These hypotheses were upheld by Van Meter's (2001) study. Participants in the most supported drawing condition scored higher on free recalls than did participants in the control condition. There were no condition effects on the recognition posttest. Furthermore, analysis of verbal protocols revealed that learners who made drawings engaged in more self-monitoring events than learners who did not draw; learners who drew with the most extensive support also engaged in more self-monitoring events than those who drew without support.

The study reported in this article is a continuation of the research reported by Van Meter (2001). Again, experimental drawing conditions test the benefits of provided support and posttests are designed to illustrate the characteristics of the knowledge acquired when the drawing strategy is used. The current study, however, is grounded in a theoretical model of the cognitive and knowledge representation processes that underlie drawing. The result has been methodological changes with respect to both the design of the control condition and the higher-order posttest employed. Specifically, the current design employs a non-drawing control condition in which participants are forced to process illustrations and includes a problem solving, rather than a free recall, posttest. The theoretical model in which this design is grounded is presented in the following section.

1.2. A model of learner-generated drawing

1.2.1. The generative theory of drawing construction

Van Meter and Garner (in press) present a processing model of drawing construction that is an extension of Mayer's Generative Theory of Textbook Design, a model proposed to explain learning from illustrated text (Mayer & Sims, 1994; Mayer, Steinhoff, Bower, & Mars, 1995). In Mayer's model, readers select key elements from text and illustrations and organize these to form coherent verbal and nonverbal representations. These two representations are then integrated to form a mental model that supports conceptual transfer (Mayer, 1993; Mayer, Bove, Bryman, Mars, & Tapangco, 1996).

The model proposed by Van Meter and Garner (in press) is fundamentally consistent with Mayer's descriptions of selection, organization, and integration and is similarly grounded in Paivio's dual-coding theory (1986, 1991). When applied to drawing, however, important differences emerge with respect to the construction of the nonverbal representation and the integration of the verbal and nonverbal representations. In addition, the drawing model addresses the role of externally provided support. Each of these aspects of the model, and how these connect with current research hypotheses, is highlighted in the following model description.

Consistent with Mayer's model of learning from illustrated text, the task of drawing begins with the selection of key elements. When learners draw with no provided illustration, however, only elements from the verbal text are available for selection. Selected elements are then organized to construct a verbal representation of text. In the organization process, elements are linked within the verbal representation as the learner activates old, and generates new, associative connections between verbal elements (Mayer, 1993; Mayer & Sims, 1994).

The selection and organization of verbal elements are crucial processes in the drawing strategy because it is the verbal representation that serves as the foundation for the construction of the nonverbal representation. Construction of this representation begins as the learner activates stored referential links between selected verbal elements and stored nonverbal representations of these. The reader who learns that the bones of a bird's wing are similar to the human arm, for example, can also activate a stored image of the human arm and use this as part of the nonverbal representation.

It is also possible, however, that drawing requires the learner to nonverbally represent elements for which no stored imagen, or nonverbal mental representation of the element (Paivio, 1991; Sadoski & Paivio, 2004), exists. In these cases, the learner relies on the verbal description to generate a nonverbal representation. When reading that barbules are "hooks and catches," for example, the reader must use stored images of hooks and catches and adapt these to the feather structure. The verbal description is the foundation for this construction.

The verbal representation is also the foundation for organizing the nonverbal representation. The spatial relationship between barbules and feathers that a learner represents in a drawing, for instance, is based on the verbal description that barbules hold separate feathers together. Although construction of the nonverbal representation is dependent on the verbal representation, the two mutually influence one another. For example, when reading, the learner may not have attended to the verbal description of barbules. When drawing, however, this learner realizes the need to determine the spatial location of this structure and this realization leads to a reinspection of the text and selection of spatial information for inclusion in the verbal representation. Once represented verbally, this knowledge is available to the nonverbal representation and subsequently, can be included in the drawing.

To envision the processes of this model, imagine a reader using drawing to learn about a bird's wing. Upon reading that the bones of a wing are much like those of the human arm and include a shoulder, elbow, and wrist, the reader selects human arm, shoulder, elbow, and wrist as key elements. Using prior knowledge of the human arm, the learner is able to organize these elements to construct a verbal representation. Under instructions to draw, nonverbal representations of these elements are also activated through referential connections between stored verbal and nonverbal representations. As reading continues, these representations are updated. In this process, the learner encounters concepts for which no stored imagen exists. In these cases, the verbal description is used to generate new nonverbal representations.

Elements in the nonverbal representation are organized according to associative connections between imagens. Again, some of these are stored links while others are newly generated. The nonverbal representation then serves as the internal image the learner depicts in a drawing. The entire process is a recursive one. Efforts to draw, for example, may cause the learner to realize that the nonverbal representation does not include information about how feathers are connected to the wing. Consequently, the learner is redirected to the verbal representation and, if the information has not been encoded there, text reinspection will follow. This recursive process supports readers' self-monitoring and increases the detection of comprehension errors (Van Meter, 2001).

1.2.2. Construction and integration processes

It should be evident at this point that integration is a substantially different process when learners read and draw rather than read and inspect provided illustrations.

When illustrations are provided, two independent representations, verbal and nonverbal, are organized and then linked to form a mental model when text and illustrations are presented contiguously (e.g., Mayer et al., 1996). Other researchers, however, have questioned whether contiguity is a sufficient condition for integration to occur (e.g., Ainsworth, 1999; Kozma, Russell, Jones, Marx, & Davis, 1996). Tabachneck-Schiif and Simon (1998), for example, found that college students did not integrate text and a graphic representation when learning economic supply and demand principles. Scevak and Moore (1990) concluded that high school participants do not integrate text and maps unless experimental manipulations force them to do so. In sum, many researchers have concluded that learners struggle with the task of translating between, and integrating, varying external formats (Ainsworth, 1999; de Jong et al., 1998).

Such conclusions raise the possibility that illustrations may improve text learning not through integration but rather through storage of independent verbal and nonverbal representations. Specifically, learners may organize verbal and nonverbal representations without engaging in the additional process of integration unless experimental manipulations force this integration. Without integration, performance on some outcome measures may be improved because the learner can access either representation to locate needed information without necessarily integrating the two. Tabachneck-Schiif and Simon (1998), for example, discuss instances in which learners struggled to coordinate two representations during reasoning though representations could be used independently.

Drawing, by contrast, demands integration because the only way for a reader to construct a drawing is by building a nonverbal representation that is derived from the verbal representation (Van Meter & Garner, in press). Past drawing research has not tested this assertion. Although Van Meter (2001), for example, compared drawing to illustration inspection, the design of that study did not ensure that control participants carefully examined illustrations. The study presented here does examine this possibility, however, by forcing non-drawing control participants to process illustrations along with text. Specifically, non-drawing control participants in this study answer questions that direct the comparison of text and provided illustrations. This manipulation ensures that illustrations are attended to and that same elements are processed in both representations. If this processing is sufficient for integration and construction of a mental model, then no additional benefits of drawing should be found. Conversely, if drawing supports integration, drawing participants should perform better on a problem solving posttest in comparison to participants who process illustrations.

In addition to integration, construction processes are also altered when learners draw (Van Meter & Garner, in press). Although several differences have already been noted, specific attention should be paid to the constraint mechanisms available to guide construction. By constraint mechanisms, we mean the internal and external representations and processes that are available to guide learning and knowledge acquisition. To illustrate, consider the processes of representing barbules described earlier. In this example, the hypothetical learner had failed to select verbal elements depicting the spatial location of barbules and thus, could not draw the structures in connection to one another. It is possible, however, for the learner not to detect the missing element and simply draw several feathers without connecting them. In this event, the error would be passed onto the final mental model and, in this case, the error would prove fatal to an accurate systems-level understanding: tight connections between feathers are necessary to prevent air from passing through the wing. In this situation, a provided illustration may act as a constraint. When inspecting the illustration, the learner may notice that feathers are connected and thus, select and encode the barbule structures as part of the nonverbal representation.

The role of constraint mechanisms ties to the need for provided support when using a drawing strategy. Alesandrini (1981), for example, found that instructions to draw were not sufficient to improve college students' learning of electrochemistry concepts. Instead, learners required additional instructions to attend to how each structure fits into the complete system. Applied to the example above, elaborated instructions of the type used by Alesandrini would direct learners' attention to the structures that connect one feather to another. These findings are consistent with Van Meter's (2001) comparison across drawing conditions. In the study by Van Meter (2001), only learners who drew with support acquired more knowledge than did non-drawing controls. Furthermore, increasing the support provided also increased the number of comprehension errors participants detected relative to the number detected by those who drew without support.

Provided support may act as a constraint that aids the learner in the construction and integration of representations of to-be-learned content. Although few studies have systematically examined the role of drawing support, Van Meter and Garner (in press) concluded that support functions in at least one of three different ways. Support may act to: (1) constrain the construction of drawings (e.g., Lesgold et al., 1975); (2) prompt checking the accuracy of constructed drawings (Van Meter, 2001); (3) and/or direct learners' attention to key elements and the relationships amongst these (Alesandrini, 1981). The study reported here systematically varies provided support across drawing conditions. By comparing supported drawing conditions to an unsupported drawing condition, evidence regarding the necessity of support is obtained. By comparing two drawing conditions with differing degrees of support, conclusions can be drawn regarding the amount of support required to be effective.

Another available constraint, or form of support, is the learner's prior knowledge. A learner with prior knowledge of human arm bones, for example, can use this knowledge for guidance when drawing the bones of a bird's wing. On the other hand, the learner who lacks prior knowledge of air flow may miss the importance of including a structure to connect feathers to one another. When drawing, learners directly benefit from nonverbal prior knowledge as well. An elementary school student may lack prior scientific knowledge of keratin and feather sheaths, for example, but that student has probably picked up a feather found lying on the ground before. In examining the feather, nonverbal representations of the feather sheath and keratin are formed although the student does not know the verbal labels. When drawing, however, this nonverbal knowledge would be activated as the student generates an image of a feather and verbal labels can be integrated with the relevant structures. In the study reported here, a pretest was included to control for these prior knowledge effects. By controlling for prior knowledge differences, and minimizing this form of support, the role of externally provided support can be more carefully examined.

1.3. Developmental differences

An area that has been neglected in previous drawing research is differences in drawing effectiveness across grades. Most research has used college student participants and we have located no text-learning research in which drawing was compared across grade levels. There may be important developmental differences that influence the efficacy of drawing across different aged learners, however. In one of the few drawing studies with young participants, for example, Lesgold et al. (1975) found that first grade participants required extensive support before drawing operated to improve learning. Given that research on other strategies has found differences in strategy effectiveness across grade levels (Pressley & Van Meter, 1993), it is important to explore the possibility that there are also age-related effects tied to drawing. To test for these differences, the current study includes both fourth and sixth grade participants. These grade levels were selected because students of this age are typically expected to acquire knowledge from reading content area text. The age-related hypothesis is considered exploratory, however, as little relevant research exists on which to base a prediction. It is expected, however, that although fourth grade participants will benefit from drawing, these participants will require more extensive support than their older counterparts.

1.4. Research hypotheses

The four experimental hypotheses tested in this study are:

1. Participants who use a drawing strategy will acquire more knowledge from text than participants who do not use a drawing strategy.
2. Participants who use a drawing strategy with support will acquire more knowledge from content area text than participants who draw without support.
3. Benefits of a drawing strategy will be found on a problem solving assessment but not on a multiple-choice recognition assessment.
4. To use drawing effectively, sixth grade participants will require less support than fourth grade participants.

2. Methods

2.1. Participants

Participants were 69 fourth and 66 sixth grade students from the rural Midwest. The fourth grade cohort included 31 males and 38 females; there were 37 male and 29 female sixth grade participants. The population was nearly exclusively Caucasian and no participants spoke English as a second language. A total of six classrooms, three at each grade level, from one private and two public schools participated. To control for any differences across schools, participants were randomly assigned to conditions across schools. Written parental consent was obtained when participants returned signed informed consent forms. Students without parental consent worked quietly at their seats throughout the experimental period.

The classroom teacher introduced experimenters and explained that participation was voluntary. Each participant gave verbal assent after assignment to experimental conditions and the experimenters' brief explanation of the experimental task.

2.2. Design

A four group experimental design, with random assignment within classrooms, was employed. The distribution of participants to condition was relatively even across schools. Within classrooms, participants were assigned to condition by having participants count off. Three experimental conditions in which participants drew with increasing levels of support were compared to a non-drawing control. The condition labels used here reflect the highest level of support that was provided. In the Draw condition, participants read a two-page science text about birds' wings. After each text page, Draw participants constructed a drawing to represent important text ideas. In the Illustration condition (Ill), participants read each text page, constructed a drawing, and inspected a provided illustration to check the accuracy of the constructed drawing. This process was repeated for the second text page. In the Prompt condition, participants read, drew, and inspected provided illustrations. Following each illustration, Prompt participants answered a series of questions designed to guide the process of comparing constructed drawings to provided illustrations. In the Control condition, participants were provided illustrations following each text page. In this condition, question sets followed each illustration. These questions were parallel to those in the Prompt condition and were designed to direct comparisons of the text and illustrations. In both the Control and Prompt conditions, participants wrote answers to these questions. Copies of the text, illustrations, and both sets of prompting questions are included in Appendices A and B.

2.3. Materials

2.3.1. Science text

The text on birds' wings included information about wing bone structure, and types, formation, and functions of flight feathers. This topic was selected because it had not been covered in the school curriculum and because scores on relevant pretest questions were neither high nor significantly different across grades. Several age-appropriate trade books were consulted and used to construct an informationally dense two-page text. The text was written at a sixth grade reading level and contained 402 words including the title. (See Appendix A for a copy of the experimental text.)

2.3.2. Provided illustrations

A pen and ink illustration followed each text page. Illustrations included labels for all structures named in text. These illustrations can be classified as representational (Alesandrini, 1984; Carney & Levin, 2002). Although spatial relations amongst structures were represented in the illustrations (Gyselinck & Tardieu, 1999), text propositions expressing ties between structural properties and functional actions were not included (Waddill & McDaniel, 1992). Thus, although an illustration accurately depicted the appearance of structures and the spatial relations amongst these structures, the illustration did not include information about function (See Appendix A for a copy of the illustrations.)

2.3.3. Pages for drawing

Learners participating in drawing conditions were given two blank $8\frac{1}{2}$ in. × 11 in. sheets of paper, one for each drawing. Only pencil and eraser were used for drawing.

2.3.4. Prompting question sets

Following each illustration, participants in the Control and Prompt conditions wrote answers to three sets of questions with two questions in each set. In the Control condition, questions directed comparison of text and provided illustrations; Prompt condition questions directed comparison of constructed drawings and provided illustrations. An example of a question set from the Control condition is: what are the three parts of the bird's wing described in the text? What are the three parts of the bird's wing shown in the illustration? The parallel question set given to prompt condition participants were: What are the three parts of the bird's wing in your drawing? What are the three parts of the bird's wing in the illustration? In both conditions, participants wrote answers to these questions in the space provided.

2.3.5. Material booklets

Booklets of experimental materials contained, in order: page one of text, a blank page for drawing, provided illustration one, the first set of questions, page two of text, a blank page for drawing, provided illustration two, and the second set of questions. Booklets prepared for each condition contained only materials appropriate for that condition. Materials were stapled down the left hand side. Blank pages for drawing were loosely inserted so these could be pulled out for drawing. Each provided illustration was covered with a blue sheet of paper to prevent looking ahead to the illustration when turning to the drawing paper. This cover sheet was stapled down the right hand side to hold it in place but, was not stapled on the left-hand side. The upper left hand corner was cut away so participants could easily pull it down to reveal the illustration.

2.4. Experimental measures

2.4.1. Pretest

A 25 question multiple-choice pretest was administered approximately one week prior to experimental sessions. Five questions each covered the topics of birds' wings, the heart, the eye, the ear, and the starfish. This pretest was used to select a topic for which there were no knowledge differences across classrooms, grades, or conditions. This test included questions directly related to the experimental text but were not the same as posttest items.

2.4.2. Problem solving posttest

The two problem solving questions were: (1) There is a bird that does not have any barbules. Would this bird be able to fly? Why or Why not?, (2) There is a bird that is experiencing a lot of turbulence in flight. What is wrong with this bird? Can it be fixed? A space for written responses followed each question.

2.4.3. Recognition posttest

The multiple-choice recognition test contained five low-level items covering a range of text points. Each question had one correct and three distractor choices; correct options were text explicit. An example of a question from this test is: The _______on a bird's feather connect all of the feathers together to form a single flat surface that air cannot pass through. The multiple-choice options for this question were, in order: barbules, sheaths, keratin, and barbs; the correct selection was barbules.

2.5. Procedures: Instructions

2.5.1. Introduction

The classroom teacher began sessions by introducing the experimenters, explaining that we were doing a research study, and explaining that participation was voluntary. The teacher then turned the class over to experimenters but remained in the room. An experimenter told participants that the study involved comparing different ways students can learn from science books; the study would tell us which way helped the most. The experimenter told participants they would be separated into different groups and each group would use a different method to study a text about birds' wings. Participants were told it was important to learn as much as possible because a test would follow after reading; test scores would decide which way of studying was the best.

Three or four experimenters were in the classroom during each experimental session with one experimenter assigned to run one experimental group. Within classrooms, participants were randomly assigned to conditions. All participants were moved so that members of each condition were seated together. Desks were grouped during experimental instructions so that all conditions were given instruction simultaneously. Later, during the experimental task, desks were moved apart to prevent copying. To ensure continuity, each experimenter followed the same script while giving instructions.

Participants were told again that the purpose of the research was to help students learn from science books. They were told that everyone would read the same text and take the same test but each group would study in a different way. Experimenters explained that it was important for everyone to work hard so that test scores could be trusted. Participants were told that the task required reading two pages of a book about birds' wings, looking at illustrations, and taking a test. Activities specific to each condition (e.g., drawing) were also mentioned in this list. Experimenters explained that booklets would be given out and that everyone should work through their booklets at their own pace. Participants were informed that there was no time limit. Verbal consent was obtained following this overview. Participants were then given instructions specific to either drawing or inspecting illustrations. These instructions are described below.

2.5.2. Drawing

Experimenters gave the following drawing instructions to participants in the Draw, Ill, and Prompt conditions:

> You are going to read a two page science book about a bird's wing and then take a test on what you read. To help you learn about the wing, I want you to draw a picture of what a wing looks like. After you finish reading each page, you will make a drawing to show what you learned on that page. Your drawing should include all of the important parts of the wing that are explained in the reading and you should try to draw it the way you think it really looks. The drawings you make are going to be like some of the illustrations in your science book. Do you have illustrations in your science book that are made to look like what you are reading about?

After this question, the experimenter waited for an affirmative response and asked participants to describe examples. The experimenter then asked, "What makes these good illustrations?" The group was prompted to name the features and conventions of illustrations including captions, labels, the realistic look, that relationships between parts are shown, and the possible use of words. After these conventions were identified, the experimenter repeated the list and encouraged participants to use these ideas in their drawings.

Participants were also asked about strategies that could be used to check the accuracy of drawings. A reread and check strategy was identified by all groups. Participants in the Ill and Prompt conditions were also told of the provided illustrations. These participants were told to inspect the illustrations after completing each drawing and to use illustrations to check the accuracy of constructed drawings. Participants in the Prompt condition were also told of the questions that would follow.

Drawing participants were then told that a blank piece of paper had been inserted in the books after each text page. After reading each text page, participants should remove the sheet of paper and, using only pencil and eraser, draw the important ideas explained on that text page. Participants were told that they could look back to the text while drawing. Participants in the Ill and Prompt conditions were specifically told not to look at provided illustrations until after drawings were completed. All drawing participants were told that changes and corrections to drawings could be made at any time, even after looking at provided illustrations.

2.5.3. Control

Parallel instructions were given to participants in the non-drawing control condition. These participants were told of the two-page text and the posttest. Instructions in this condition focused on the illustrations rather than drawing. The experimenter told participants that the text included two illustrations that were made to look like a bird's wing; each part from the text was included in the illustration. Participants were asked about illustrations in their science books that had been made to show what an object actually looked like. Consistent with experimental conditions, participants were encouraged to give examples of these illustrations. The question, "What makes these good illustrations?" was also asked and the discussion of illustration features and conventions took place. In this condition, participants were encouraged to pay attention to these aspects of provided illustrations.

2.5.4. Condition instructions

Experimenters also gave instructions specific to each condition. The instructions and the materials included in experimental booklets are described below.

2.5.4.1. Control. Participants were told to read the text pages and inspect the illustrations to learn the ideas as well as possible. Participants were also told that questions would follow each illustration and they should write answers to these questions in the space provided. Materials were two text pages, two illustrations, and two pages of questions.

2.5.4.2. Draw. Drawing participants were told that, after reading each page of text, a drawing should be constructed to represent what was learned from that page. Participants were told that any changes could be made to drawings after reading the next page of the text. Materials were two text pages and two blank sheets for drawing.

2.5.4.3. Ill. Instructions were the same as those in the draw condition. Additionally, Ill participants were told to inspect the provided illustration after completing each drawing and to use this illustration to check the accuracy of constructed drawings. Participants were told that changes could be made to drawings after inspecting illustrations but that drawings should be made as completely as possible before inspecting illustrations. Materials were: two text pages, two blank sheets for drawings, and two illustrations.

2.5.4.4. Prompt. Instructions in this condition were identical to those in the Ill condition. In addition, participants were told that questions would follow each illustration and that complete answers to these questions should be written in the space provided. Participants were told that changes to drawings, or question answers, could be made at any time after reading the text. Materials were two text pages, two blank sheets for drawing, two illustrations, and two pages of questions.

All instructions were reviewed before participants began the task. Participants were reminded to complete the task at their own pace and that, although looking back to early parts of the booklet was permissible, looking ahead was not allowed. Participants were also reminded that a test would follow the learning task and that no materials would be available during the test.

2.6. Procedures: Experimental task

After instructions were given, experimental materials were handed out and the experimenter showed the participants the different parts of the booklets. Desks were spread apart so participants could work independently. Each experimenter observed participants in a single condition to ensure that instructions were followed. Although experimenters answered questions pertaining to experimental procedures, answers were not given to content-related questions. As participants completed the learning task, the instructional booklet was collected and the posttest was given out. Participants first answered the two problem solving questions and then completed the recognition posttest. On the problem solving posttest, participants were told to write as much as possible. Posttests were not counterbalanced due to concerns that multiple-choice questions would influence performance on the problem solving measure.

The experimental task, including the posttest, required approximately 1 h. Participants in the Prompt condition typically required the most time. In comparing the time, within classes, of the last Prompt participant to complete the task to the last participant from a different condition to complete the task, Prompt participants spent up to 10 min more time. Thus, at its extreme, Prompt participants spent 17% more time on task than participants in other conditions.

2.7. Coding rubric: Problem solving

A five-point rubric was used to score problem solutions. This rubric followed the methods established by Guthrie and co-workers for scoring similar responses from elementary school participants (Guthrie, Van Meter, McCann, & Wigfield, 1996; Guthrie et al., 1998). Although rubrics for each question differed with respect to specific content, they were designed to parallel one another. The five rubric points were: (1) No conception: no answer, I don't know. (2) Inaccurate conception: misconceptions; irrelevant knowledge not derived from text. (3) Incomplete conception: sparse or irrelevant answer using knowledge derived from text. (4) Partial conception: relevant, incomplete answer using knowledge derived from text. (5) Complete conception: relevant answer is accurate and complete.

Two authors scored a subset of 30 responses to each problem with interrater agreement exceeding 90%. The first author scored the remaining problem solutions. The two problem solving scores were added to calculate total problem solving scores.

3. Results

3.1. Pretest

The pretest was used to select an appropriate topic for the experimental text. The criteria for selection required that participants demonstrate low prior knowledge overall and that there be no significant differences across grades. As shown in Table 1, scores from the five pretest items covering the bird topic were near chance. Addi-

Table 1
Means and standard deviations, across grades and conditions, for the pretest

	Control	Draw	Ill	Prompt	Total
Fourth grade					
x	1.12	.47	.88	1.05	.88
SD	(.72)	(.62)	(1.25)	(1.1)	(.98)
n	16	17	16	20	69
Sixth grade					
x	1.21	.72	1.07	.94	.97
SD	(.98)	(.83)	(.82)	(.83)	(.86)
n	14	18	14	17	63
Total					
x	1.17	.60	.96	1.00	
SD	(.83)	(.74)	(1.06)	(.97)	
n	30	35	30	37	

tionally, a t test comparing scores on these five items across grades was nonsignificant, $t(135) = 3.432$.

Pretest scores were also compared in a 2 (Grade) $\times$ 4 (Condition) ANOVA to determine if there were any significant differences between conditions on prior knowledge. There were no statistically significant difference by condition, $F(3, 127) = 2.300$ or grade, $F(1, 127) = .444$. The interaction was also nonsignificant, $F(3, 127) = .224$.

3.2. Problem solving posttest

Cronbach's α for this test was .472. Although this coefficient is low, it is acceptable for a two-item test. Using a Spearman–Brown adjustment to project reliability for a four-item version, for example, yields a coefficient of .64. Means and standard deviations, by grade and condition, on the problem solving posttest are shown in Table 2.

Scores on this posttest were submitted to analysis in a 2 (Grade) $\times$ 4 (Condition) ANOVA. The grade by condition interaction was not significant, $F(3, 127) = 2.331$. The main effects of condition and grade were statistically significant; condition, $F(3, 127) = 4.638$, $p < .004$, $\acute{\eta}_p^2 = .100$; grade, $F(1, 127) = 12.356$, $p < .001$, $\acute{\eta}_p^2 = .089$. Follow up comparisons, using a Tukey's Honestly Significant Difference (HSD) test, showed that participants in both the Prompt and Ill conditions scored significantly higher than did non-drawing controls. Sixth grade participants also had higher problem solving scores relative to fourth grade participants.

Actual condition means by grade, however, suggest there may be important practical differences between the two grades. As illustrated in Fig. 1, the mean problem solving scores of sixth grade participants increase steadily across conditions. The line depicting fourth grade participants, by contrast, is nearly flat. In fact, the average problem solving score for the fourth grade Prompt condition was only 4% higher than the average score for the fourth grade control condition. By comparison, sixth

Table 2
Means and standard deviations for the problem solving posttest

	Control	Draw	Ill	Prompt	Total
Fourth grade					
x	4.44	4.47	4.81	4.80	4.64
SD	(1.67)	(1.88)	(1.47)	(1.80)	(1.69)
MSE	.42	.46	.37	.40	.20
n	16	17	16	20	69
Sixth grade					
x	4.43	5.11	6.44	6.88	5.74
SD	(1.60)	(1.37)	(2.34)	(1.97)	(2.05)
MSE	.43	.31	.58	.48	.25
n	14	19	16	17	66
Total					
x	4.43	4.81	5.63	5.76	
SD	(1.61)	(1.64)	(2.09)	(2.13)	
MSE	.30	.27	.37	.35	
n	30	36	32	37	

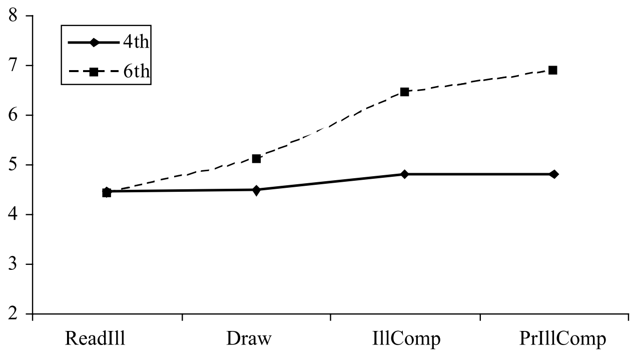


Fig. 1. Grade × Condition means for the problem solving posttest.

grade Prompt participants, on average, scored 24.5% higher than sixth grade control participants; sixth grade Ill participants averaged a 20% advantage over control participants. This pattern challenges the conclusion drawn from the statistically nonsignificant interaction; the conclusion that drawing with support leads to improved problem solving performance for both fourth and sixth grade participants. Due to this concern, separate four-group one-way ANOVAs were used to analyze problem solving scores within grades. In fact, when the scores of fourth grade participants were analyzed separately, there were no significant condition differences, $F(3, 65) = .241$. When scores for fourth grade participants were analyzed independently, drawing, even with support, did not increase problem solving scores.

When sixth grade participants' problem solving scores served as the dependent variable, the condition effect was statistically significant, $F(3, 62) = 6.046$, $p < .001$,

$\acute{\eta}_p^2 = .23$. Results of the follow up Tukey's HSD test revealed that means for the Prompt and Ill conditions were significantly higher than the mean for the Control condition. Additionally, participants in the Prompt condition generated higher quality problem solutions than participants in the Draw condition generated. There were no statistically significant differences between control participants and those who constructed drawings without support (Draw condition).

These within grade analyses show a different pattern of results than what was found when the full factorial model was tested. Although Prompt and Ill participants did score significantly higher than did Control participants, these condition effects were due primarily to the performance of sixth grade experimental participants. Fourth grade drawing participants did not score significantly higher than fourth grade control participants scored. Sixth grade participants, on the other hand, did use drawing effectively when support was provided. Not only did Prompt and Ill participants score higher than did non-drawing control participants, Prompt participants also scored higher than did participants drawing without support.

3.3. Recognition posttest

Means and standard deviations, by grade and condition, for the recognition posttest are shown in Table 3. Cronbach's α for this test was .38. Again, given the small number of items on this assessment, this reliability is reasonable.

Scores on this posttest were analyzed in a 2 (Grade) $\times$ 4 (Condition) ANOVA. In this analysis, the interaction was not significant; $F(3, 127) = 1.74$; nor were there any significant main effects; condition, $F(3, 127) = .335$; grades, $F(1, 127) = 3.814$. These results are consistent with the hypothesis that a lower-order assessment would not be sensitive to the effects of drawing either with or without support.

Table 3
Means and standard deviations for the multiple-choice, recognition posttest

	Control	Draw	Ill	Prompt	Total
Fourth grade					
x	1.69	1.82	1.25	1.45	1.55
SD	(.95)	(1.38)	(1.13)	(1.61)	(1.30)
MSE	.24	.34	.28	.36	.16
n	16	17	16	20	69
Sixth grade					
x	1.71	1.68	2.06	2.41	1.97
SD	(1.20)	(1.16)	(1.12)	(1.06)	(1.15)
MSE	.32	.27	.28	.26	.14
n	14	19	16	17	66
Total					
x	1.70	1.75	1.65	1.89	
SD	(1.06)	(1.25)	(1.18)	(1.44)	
MSE	.19	.21	.21	.24	
n	30	36	32	37	

4. Discussion

4.1. Summary of results

The results of this study are consistent with inferences drawn from the model of drawing processes. First, the prediction that drawing is a more effective learning strategy than illustration inspection was upheld. Although illustration-text comparison questions ensured that control participants attended to relevant elements in illustrations, these participants generated lower quality problem solutions than did participants who drew with support. Consistent with the second hypothesis, this was true only for drawing groups who had support, either in the form of provided illustrations or illustrations and prompting questions. Furthermore, sixth grade participants in the most supported condition scored significantly higher than drawing participants with no provided support. The prediction that condition effects would be found on the problem solving assessment, but not the recognition assessment, was also confirmed. There were no significant differences on the multiple-choice posttest.

Although the grade by condition interaction was not significant, it is our opinion that interpretations should be qualified by observed differences across grade levels. Fourth grade mean problem solving scores across conditions are not consistent with the conclusion that the two supported drawing groups scored higher on the problem solving posttest than the control group scored. In fact, on the problem solving test, there was no mean difference greater than one-half point between any of the groups of fourth grade participants. This contrasts with the two-point differences between the mean problem solving scores of sixth grade participants in the Ill and Prompt conditions compared to sixth grade participants in the Control condition. Given these patterns, we believe the conclusions from this study should be qualified by differences in strategy effectiveness across grade levels. Accordingly, these grade level differences are taken up first in the following discussion.

4.2. Developmental differences

Contrary to initial predictions, when problem solving scores were analyzed separately for each grade, fourth grade groups did not benefit from provided support. Although it was predicted that younger participants would require more support than older participants, fourth grade participants were expected to demonstrate improved learning under the most supported condition. These grade level differences cannot be attributed to either prior knowledge or general comprehension ability. First, with respect to prior knowledge, there were no significant differences across grades on the pretest. In fact, the pretest mean for the fourth grade prompt group was actually slightly higher than the pretest mean for the sixth grade prompt group. The alternative hypothesis that grade level differences in this study were due to the difficulty of the text is also not supported. If the experimental text were too difficult for fourth grade participants, lower scores would be expected for all fourth grade groups on both posttests. This was not the case, however. On both the recognition and the problem solving posttests, mean scores for fourth and sixth grade control participants were nearly identical; the differences were .02 and .01, respectively.

The grade level differences found in this study suggest that drawing operates differently for younger, compared to older, learners. More research is needed, however, to further test these findings and incorporate age-related differences into the model. Although, for example, the support provided in this study was not sufficient, it is not clear if fourth grade learners would benefit from an even greater degree of support. Perhaps, for example, students of this age could use the strategy more effectively if instructions were more elaborated or practice and feedback opportunities were provided.

4.3. The generative theory of drawing construction

Research hypotheses regarding the efficacy of drawing, the need for support, and appropriate assessments were directly derived from the proposed model of the drawing process. In this model support is believed to be necessary because of the constraint opportunities it provides. In this study, the only constraints available to learners drawing without support was the text and the learners' limited prior knowledge. The results show that this was not sufficient for drawing to improve learning and this was consistent with previous research (Van Meter, 2001). Given the opportunity to inspect provided illustrations after drawing, however, supported sixth grade groups did score higher on the problem solving posttest. These findings are interpreted as consistent with the constraint mechanism assumptions of the model.

Increasing the degree of provided support also increased learning in this study. Specifically, sixth grade participants who drew with both illustrations and prompting questions obtained higher scores on the problem solving posttest than did participants who drew without support. Although those who drew with only illustrations for support did score significantly higher than non-drawing controls, this group did not score higher relative to the group drawing without support. This pattern mirrors the pattern reported by Van Meter (2001) with respect to self-monitoring events. Van Meter (2001) found that the most supported drawing group engaged in self-monitoring processes more frequently than did the unsupported drawing group. These patterns raise the possibility that there is an interaction between drawing and guided illustration inspection that supports learning beyond either process alone. In the context of the drawing model, constraint mechanisms are credited for this interaction. These mechanisms act to guide comprehension and constrain understandings such that an increase in support influences both self-monitoring and the accuracy and completeness of acquired knowledge.

Methodological changes with respect to the non-drawing control group in this study, compared to Van Meter (2001), provide stronger evidence for the claim that drawing benefits learning beyond illustration inspection. Because Van Meter (2001) did not force control participants to process illustrations, it is possible that the condition effects in that study were due to illustration processing rather than drawing. That is, instructions to draw may simply have acted as a means to force attention to the illustration. The current design of the control condition permits us to rule out this hypothesis. By requiring non-drawing control participants to write answers to illustration-referencing questions, there is assurance that these participants did process the illustrations. Furthermore, because question sets in the Control condition paralleled those in the Prompt condition, there is also assurance that control participants attended to relevant features of the illustration. Thus, the results of this study support the claim that drawing can be a more effective learning strategy than merely inspecting illustrations.

In the Generative Theory of Drawing Construction, the drawing process model presented here, integration is the specific process credited for the additional benefits of drawing (Van Meter & Garner, in press). When learners must draw, this activity not only forces the engagement of nonverbal representational processes, it does so in a manner that necessarily leads to integration across verbal and nonverbal modalities. Learners can construct drawings only if they first derive a nonverbal representation from the verbal representation.

This integration assumption has direct implications for the type of assessment likely to reveal the benefits of drawing. When learners integrate representations, particularly across modalities, a mental model results (Mayer & Sims, 1994). Defined as an elaborated representation, a mental model affords more flexible applications of acquired knowledge (de Jong et al., 1998; Kintsch, 1994) but does not retain the verbatim textbase (Mayer, 1993; McNamara et al., 1991). Subsequently, a learner who has constructed a mental model of target content will have an advantage on higher-order assessments that require knowledge application or transfer but will not necessarily have an advantage on assessments that rely on verbatim recognition.

The results of this study are consistent with these assumptions. All significant condition effects were found when problem solving scores served as the dependent variable. There were no significant condition effects when recognition scores were compared. Taken together, these patterns support the hypothesis that, when learners make drawings of to-be-learned content, the integration of verbal and nonverbal representations results in construction of a mental model.

5. Conclusions

Overall, the results of this study support hypotheses derived from the Generative Theory of Drawing Construction. The addition of external support allowed learners to use drawing effectively to improve learning from content area text. Much remains unknown about drawing as a learning strategy, however. One specific question raised by the findings of this study is the possibility that there are important grade level differences in how drawing operates. Although in this study there is an indication that drawing is not effective for younger learners, at this time these findings should not be generalized beyond this study. Rather, the results of this study indicate a clear need for additional research to better understand developmental differences that interact with drawing.

Additional research is also needed to better understand the nature of required support. In the drawing model presented here, support functions as a constraint mechanism that guides learners through the construction of integrated verbal and nonverbal representations. At this time, it is not clear, however, exactly how this constraint mechanism operates. As Van Meter and Garner (in press) propose, there are at least three different possible support functions. Direct comparisons of these may shed more light on precisely how various types of support constrain the learning process and interact with drawing. Results from these comparisons can be incorporated into the drawing model to inform the design of more effective uses of learner-generated drawing. Along with these comparisons, prior knowledge should be investigated as a potential constraint mechanism. Particularly, it will be important to consider both verbal and nonverbal forms of prior knowledge.

On the whole, this study supports the use of drawing as a strategy for learning from content area text. Upper elementary school participants learned more when a supported drawing strategy was used. Given the challenge of acquiring knowledge from content area text (National Reading Panel, 2000; RAND Reading Study Group, 2002), particularly for learners of the age studied here, drawing has the potential to be a valuable tool. To realize this potential, however, more research is needed. The Generative Theory of Drawing Construction should serve as a guide in the development of this research. By using this guide, drawing research may proceed systematically to answer the questions necessary to move from potential to practice.

Appendix A. This appendix contains the experimental text and illustrations

A.1. A bird's wing

The bones and feathers of a bird's wing are made to help the bird fly. The bones of a bird's wing are very much like the bones in a human arm. The bird has an upper arm between the shoulder and elbow, a lower arm between the elbow and the wrist, and a hand. Connected to the wing bones are long flight feathers. The longest flight feathers, called primary feathers, are attached to the hand section. Most birds have 10 primary feathers on each hand. Primary feathers produce the power for flight as the bird brings its wings downward. The primaries on the outside can be used for steering, like the flaps on an airplane.

The secondary feathers are not quite as long. They are attached to the lower arm bones. The number of secondaries depends on the length of the bird's wing. Secondary flight feathers are curved from the front of the bird to the back. This produces an airfoil profile, like an airplane wing, that pulls the bird upward as it flaps its wings through the air. This upward pull is what allows the bird to lift itself into flight.

Other feathers, called tertiary feathers, close the gap between the elbow and shoulder. These tertiary feathers shape the wing into the body to keep the bird steady during flight. This unsteadiness or, irregular motion, is called turbulence. A bird can beat its wings at the shoulder, the elbow, and the wrist.

--Page 2

A bird's feathers are made of a protein called keratin. It is this protein which gives the feathers their great strength and flexibility. A new feather is made when a shaft of keratin begins to grow through a tube, called a feather sheath, on the edge of the bird's wing. As this shaft grows, the protein dies and begins to split apart into barbs. These barbs are the colored part of the feather. Eventually, the shaft begins to grow out through the top of the feather sheath and the barbs unfold to form the flat surface of the feather. To work effectively in flight, these barbs most form a single, continuous, flat surface for air to flow over. This surface is produced by thousands of hooks and catches at the end of each barb. These hooks and catches, called barbules, are found on either side of each barb and lock the barbs of each feather together.

Illustration 1

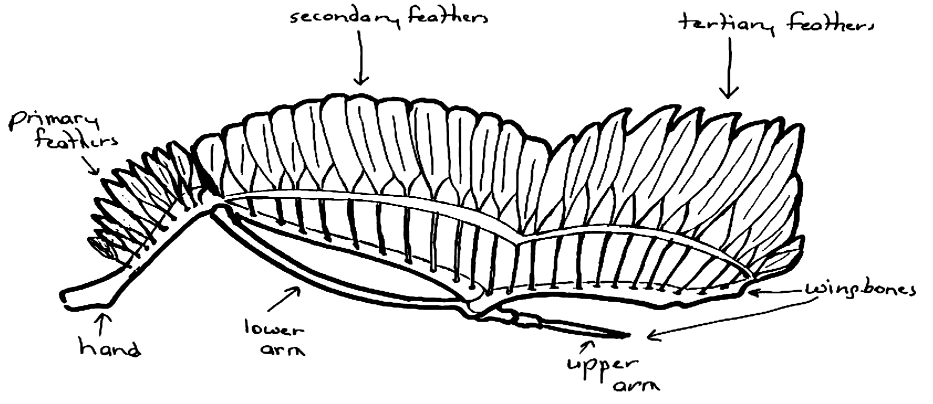
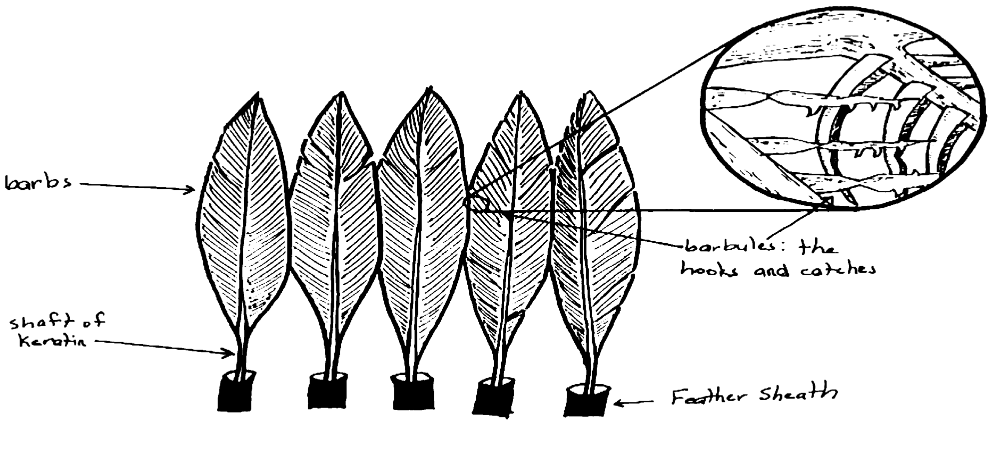


Illustration 2



Appendix B.

This appendix contains the prompting questions used in the Control and Prompt conditions. In the Control condition, each question set followed the format of asking what the requested information was in the text and then what this same information was in the illustration. In the Prompt condition, each question set followed the format of asking what the requested information was in the constructed drawing and then what this same information was in the provided illustration. These two questions were then followed by the question, ''Is there anything in your drawing you would like to change?'' The requested information for each text and illustration page were:

Page 1

1. What are the three parts of the bird's wing?
2. What are the three types of feathers on a bird's wing?
3. How are the feathers on a bird's wing shaped to help it fly?

Page 2

1. What part of the wing does the keratin grow through to form a new feather?
2. How is the colored part of feather formed?
3. What do the barbules on the end of a feather look like?

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