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The Self-explanation Principle

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Abstract

Learning in multimedia environments is hard because it requires learners to actively comprehend and integrate information across diverse sources and modalities. Self-explanation is an effective learning strategy that helps learners develop deep understanding of complex phenomena and could be used to support learning from multimedia. Researchers have established the benefits of self-explaining across many domains for a range of ages and learning contexts (including multimedia situations). This research demonstrates that some learners are natural self-explainers and also indicates that learners can be trained to self-explain. However, even when trained, there remain large individual differences in effective self-explaining. Additional support, which may be afforded by multimedia environments, appears to be needed for engaging some learners in this activity. This chapter reviews related literature and explores the relationship between multimedia learning and self-explaining.

Multimedia learning environments have the potential to substantially improve student learning compared to single media (Mayer & Moreno, 2002; Najjar, 1996). Controlled studies that compare multimedia (e.g, combinations of text and illustrations or narration and animation) with single media resources have found that students learn better from a combination of media, provided that the materials are well-designed (Goldman, 2003; Mayer, 1993; Mayer & Anderson, 1991; Mayer & Gallini, 1990; Mayer, Heiser, & Lonn, 2001).

Two distinct advantages of multimedia resources over single media are that different modes and types of external representations can provide both unique perspectives and tailored descriptions. For example, text and narrations present information in a verbally encoded linear sequence whereas illustrations or pictures present information simultaneously. In addition, text may be a more effective means for describing abstract and general information whereas illustrations and animations are particularly effective at conveying spatial configuration or dynamic information. These complementarities of information, tailored to a suitable modality (oral or visual) and/or format (text or illustrations), may explain the advantage of learning from multimedia over a single media.

However, in order to benefit from multimedia descriptions, the learner must actively construct a conceptual knowledge representation that relates and integrates different kinds of information from diverse sources and modalities into a coherent structure (Schnotz & Bannert, 2003). Using eye movement data of students' on-line processing of multimedia materials describing a functional system, Hegarty and Just (1993) have shown that in order to form a complete mental model of the device, readers need to process both media (i.e., text and diagrams). Readers do this by gradually integrating information across media from a local representation of several subparts of the system to a more global representation of the entire system. Other studies have confirmed this general need to integrate information across representations in order to construct a deep understanding (Ainsworth, Bibby, & Wood, 2002; Chandler & Sweller, 1991; Glenberg & Langston, 1992; Hegarty & Just, 1989).

However, merely exposing learners to rich multimedia descriptions does not automatically result in deep comprehension and learning (Kozma, 1994). For example, some learners may be passive in the way they process multimedia (Guri-Rozenblit, 1989; Reinking, Hayes, & McEneaney, 1988). The processes of selecting, organizing, translating, coordinating, and integrating information across modalities and formats that are necessary to learning in a multimedia context may be difficult for learners (Ainsworth, 1999).

In short, learning in multimedia environments is potentially very effective, but only if learners engage in the demanding behaviors of constructing, integrating, and monitoring knowledge in an ongoing manner. Thus, to benefit from the advantages of multimedia resources, one challenge is to engage learners in the active knowledge construction and monitoring processes necessary for learning. However, this challenge may be mitigated by the possibility that multimedia environments, especially well-designed ones, might actually be more natural environments for supporting constructive activity, as compared to a single media environment. In this chapter, we explore the hypothesis that one affordance that multimedia environments provide is to naturally support student’s ability to engage in knowledge construction and monitoring activities. We investigate this hypothesis in the context of one constructive activity that has been shown to be effective in learning—self-explaining.

We begin with a brief review of self-explaining, followed by an example of how self-explaining can mediate learning in a multimedia context. We then provide a brief analysis of why multimedia environments might be particularly suitable context for self-explaining, along with a presentation of data across several studies showing that multimedia environments seem to serve as a more effective context for supporting students ability to generate self-explanations than a single media. We end with some ideas to consider about the characteristics of a well-design multimedia environment.

Self-explaining

Self-explanation is a domain general constructive activity that engages students in active learning and insures that learners attend to the material in a meaningful way while effectively monitoring their evolving understanding. Several key cognitive mechanisms are involved in this process including, generating inferences to fill in missing information, integrating information within the study materials, integrating new information with prior knowledge, and monitoring and repairing faulty knowledge. Thus, self-explaining is a cognitively demanding but deeply constructive activity.

The effectiveness of self-explanation

Self-explaining was originally postulated as a potential learning activity in trying to understand how students are able to learn successfully from texts materials that are incomplete. Learning materials often include informational gaps or omissions both in the text passages (Chi, de Leeuw, Chiu & LaVancher, 1994) as well as in descriptions of the steps involved in worked-out problem examples (Chi, Bassok, Lewis, Reimann & Glaser, 1989).

The general procedure used in studies of self-explanation is to have a group of learners spontaneously explain the meaning of each sentence of a passage as they study some target domain. The learners' explanation protocols are then coded into several statement types. The coding schemes typically include categories for "low quality" statements like those that involve simply rereading or paraphrasing and categories for "high quality" statements such as those involving tacit knowledge that links pieces of explicitly stated text, or inferences that fill information gaps, and so on (Chi, 2000). In some cases the explanations are knowledge monitoring statements. Throughout this chapter, we use the term *high quality self-explanations* to refer to statements that demonstrate the generation of inferences, integrating statements, and various comments that reflect deep analyses of the resources; and *low quality self-explanation*s to refer to paraphrases and re-reading statements.

Once the protocols have been coded, learning gains are correlated with the frequency and quality of self-explanations demonstrated. Such studies find high quality self-explanation to be positively related to leaning gains across a wide variety of domains and tasks, including solving problems in physics (Chi & Bassok, 1989), Lisp programming (Pirolli & Recker, 1994; Recker & Pirolli, 1995) and logic (Neuman, Leibowitz, & Schwarz, 2000). Below, we review several key studies in more detail to highlight some of the important findings regarding the use and benefits of engaging in spontaneous self-explaining.

In the original self-explanation study, Chi, Bassok, Lewis, Reimann, and Glaser (1989) had students talk aloud as they studied worked-out physics examples involving a mix of text and diagrams prior to solving problems. Students were classified as "good" or "poor" learners based on their post problem-solving scores. An analysis of the worked-out examples suggested that several important reasoning steps were missing from the study materials. When the protocols of more effective learners were compared to those of the poorer learners, it was found that students who spontaneously generated a larger number of high quality self-explanations while studying the incomplete worked examples scored twice as high on a post-test than students who generated many fewer high quality self-explanations. Good learners generated more inferences that linked new text material to examples and to their prior knowledge, and generated more task related ideas that made more references to central domain principles. The poor students, on the other hand, generated low quality self-explanation behaviors such as generating paraphrases and re-reading the materials without generating any inferences. Furthermore, the good students demonstrated more frequent and accurate monitoring of their understanding, whereas the poorer students tended to overestimate their understanding. Thus, worked examples that omitted several reasoning steps were not detrimental to learning provided that the learners actively explained the examples to themselves.

A similar pattern of results were obtained by Fergusson-Hessler and de Jong (1990) who investigated the study behaviors of “good” and “poor” achieving students assigned to learn physics by studying a text book (again using a mix of text and diagrams). They found that while both “good” and “poor” students engaged in an equal number of study processes, the good students tended to use deeper strategies (including integrating information, making relationships explicit, and imposing structure) whereas poor students were more likely to use behaviors that resulted in superficial processing (e.g., re-reading).

Again, using worked examples of probability problems involving a text and formulae, Renkl (1997) found a significant learning benefit associated with generating self-explanations, even after the effects of time on task was controlled. He distinguished two separate styles of successful self-explanation, and two unsuccessful styles. The most successful gainers (*principle-based explainers*) tended to employ explanations relating operators to domain principles, while the second cluster of successful learners (*anticipative reasoners*) tended to have more prior knowledge and to anticipate computations before viewing them. Unfortunately, most learners were either *passive* or *superficial* explainers and were less successful solvers.

This line of research shows two robust findings. First, it validates the effectiveness of self-explaining as a constructive activity in the context of learning. The depth to which learners engage in this activity is a significant predictor of the learner’s ability to develop deep meaningful understanding of the material studied. Second, it demonstrates that learners differ in the degree to which they spontaneously self-explain while studying worked examples or reading text.

Because many of the studies reviewed are correlational in nature, they potentially confound the tendency to engage in high quality self-explanation with other important learner variables such as prior knowledge, motivation, or ability. That is, students who spontaneously demonstrate a high degree of quality self-explaining may simply be better learners who are able to engage in this activity regardless of the informational context. Additionally, the quantity and quality of self-explanation and learning across various instructional formats is not directly addressed by such studies. Thus, we cannot tell directly whether the utility of self-explaining varies with learning context (i.e., learning from single vs. multimedia). In the next section we review research that explores the utility of encouraging or training students to use self-explaining strategies. This approach allows researchers to go beyond correlational analyses and provides some insights into the problem of how to design learning environments that support self-explaining.

Self-explanation as a trainable learning strategy

Experimental studies that involve the use of random assignment to a prompted or trained group versus a control group address many of the problems described above. A number of such studies have been conducted in order to assess the effectiveness of designing instructional means to foster effective self-explanations. In general, these studies indicate that self-explanation can be successfully prompted or trained rather than spontaneously generated with similar learning benefits.

Chi, de Leeuw, Chiu, and LaVancher (1994) experimentally compared a prompted to an unprompted group of learners reading a text on human circulatory system. The prompts were designed to encourage students to analyze the text, to attempt to explain it to themselves, and to encourage learners to monitor their comprehension of the material. The prompted group demonstrated significantly greater learning improvements relative to the control group, particularly for the most difficult questions (those requiring deep domain knowledge). Thus, this study demonstrates that self-explaining can be beneficial even when it is explicitly elicited.

Training can also benefit middle school students' ability to generate high quality self-explanations and thereby improve their learning. Wong, Lawson, and Keeves (2002) trained middle school students to use self-explanation strategies and compared this group to a control group of students who used their usual studying techniques in a subsequent transfer session in which they studied a new geometry theorem involving text and diagrams. Both groups attained equal mastery on a domain-specific knowledge test following completion of training. However, the self-explanation group demonstrated a positive and sustained advantage on problem solving performance, particularly for solving the most difficult problems. The self-explanation training facilitated the students' ability to later access and use knowledge and to self-monitor during study of new geometry theorem, and this in turn affected subsequent problem solving performance for near and far transfer items.

A variety of training procedures have been used across several domains and learning contexts. They range from simple prompting in learning from text in the domain of biology (Chi, et al., 1994), learning engineering in a web-based course (Chung, Severance, & Chung), and learning to solve statistics word problems (Renkl, Stark, Gruber, & Mandl, 1998) and geometry problems (Aleven & Koedinger, 2002), to giving a pre-question to guide learners' self-explanations in multimedia environments (Mayer, Dow, & Mayer, 2003), to directly training students how to engage in high quality self-explanation and self-regulation strategies in the domain of programming (Bielaczyc, Pirolli, & Brown, 1995), to very elaborate training and practice in self-explaining and strategy identification for learning from science text (McNamara, in press). These studies show unambiguously that learners can be trained to self-explain.

Individual differences in self-explaining.

Although self-explaining has been shown to be an overall effective strategy that promotes learning, there are robust learner differences in terms of either the amount or quality of self-explanations generated. Such individual differences hold whether students are free to spontaneously generate self-explanations or whether they are prompted or trained to self-explain.

In the studies reviewed above, we have already discussed the fact that more successful learners tend to generate more and better quality self-explanations. For example, even within the prompted group in the Chi et al., study (1994), some students generated many more self-explanation inferences (the high self-explainers) than other students (the low self-explainers), and on a posttest the high explainers were able to answer more complex questions correctly and were better able to induce the correct mental model of the circulatory system. Similarly, when Conati and VanLehn (2000) implemented a self-explanation coach to scaffold students' attempts to generate explanations as they learned physics problems, the level of assistance necessary for generating self-explanations varied with the student's prior knowledge. Novice students benefited from highly structured help for self-explaining whereas experts needed less support. In agreement with this finding, McNamara (in press) reported that an elaborate training procedure in self-explaining and reading strategy use significantly helped low prior knowledge readers to generate quality self-explanations and to comprehend a transfer text, but did not significantly alter the performance of high prior knowledge readers compared to untrained controls. Thus, individuals may require different amounts of situational support in order to engage in a cognitively demanding constructive activity like self-explaining.

Such support must go beyond simple methods like merely encouraging learners to talk aloud which does not in itself lead learners to generate effective self-explanations. For example, Teasley (1995) compared children's performance on a scientific reasoning task for those working alone to those in dyads, and who were instructed to either talk as they worked or not. She found that the type of talk rather than amount was significantly related to improved performance. Specifically children who worked in dyads and demonstrated more interpretive forms of talk that related to the deep structure of problems were the ones who demonstrated the greatest improvements. Thus, effective situational supports for self-explaining must encourage learners to engage in appropriate constructive activity.

Self-explaining vs. other types of explaining

It should be emphasized that self-explaining is a self-generated and self-directed constructive activity that makes knowledge personally meaningful and thereby distinguishing it from other constructive learning activities such as explaining to another or summarizing (Chi, 2000). Self-explanations can have many peculiar characteristics, including the possibility that they can be fragmented, incorrect, and incomplete. Thus, self-explanations are definitely not formal, complete explanations that are deductively closed. For example, explanations directed to oneself are qualitatively different from explanations directed at another. Explanation directed at another may be more complete, may take the listener's knowledge into account, and may also reflect only what the explainer understands; whereas self-explanations tend to be focused on what the learner him/herself does not understand. To the extent that self-explanations can be viewed as efforts to repair one's own misunderstanding (Chi, 2000), self-explaining should be a more powerful learning activity than generating explanations directed at others or directed by others. The results of the following studies support this conjecture.

O'Reilly, Symons and MacLatchy-Gaudet (1998) compared the effectiveness of two different learning strategies (self-explanation and elaborative interrogation) to a control group. The self-explanation group was encouraged to explain a biology text and explicitly relate the text content to their prior knowledge while the elaborative interrogation group was encouraged to answer questions about "why" certain facts in the text made sense (i.e., a much more traditional form of explanation). In other words, they were directed to explain some facts chosen by the experimenter. The self-explanation group, demonstrated significantly greater learning gains than either of the remaining groups demonstrating that when learners self-directed their explanations in terms of relating new information to their own knowledge, they learn better than when they were directed to explain by another.

Self-directed explanations are also more effective than explaining directed at another. Mwangi and Sweller (1998) found that when 3rd and 4th graders were asked to "self-explain" to an imaginary child as they solved an arithmetic word problem, there was no significant benefit compared to a control group that did not explain. Although their study did not directly compare self-directed explaining to other-directed explaining, the results can be interpreted to suggest that self-explaining is more effective. Roscoe and Chi (2003), however, did directly compared self-directed explaining to other-directed explaining in college students. We found that self-explaining was significantly better at improving learning than explaining directed at another, whether the “other” is a listener who is either physically present or a potential future listener.

There is, moreover, another variation of self-directed explanation that seems more powerful than the originally conceived self-explanations. In this version, young children were asked to self-explain either their own or another’s (the experimenter’s) answers to solve number conservation and mathematical equality problems (Siegler, 2002). Siegler reasoned that explaining another person’s answers *could* be more effective than explaining your own if the other person’s answers are consistently correct, and your answers include some incorrect responses. In line with his predictions, children who showed the most success in explaining the experimenter’s reasoning were also the ones who showed the greatest increases in generating correct answers on their own. His results demonstrate an advantage to having to explain a variety of performance models.

There are two ways to interpret Siegler’s results. One way is to say that his results are completely consistent with our repair view. That is, explaining another person’s reasoning, especially a more correct one, raises additional opportunities for comparing and contrasting the other person’s reasoning with one’s own. Any conflicts observed will naturally elicit more repairs of one's own representation (Chi, 2000). A second compatible way to interpret his results is that explaining another person's correct reasoning is not unlike explaining a text sentence or passage. But the advantage over explaining a text passage might be that a peer's reasoning might be more transparent than a text's. In any case, exposing a learner to multiple perspectives on a problem (or perhaps even multiple representations of a problem solution), either from a text or from another peer's reasoning, seems to support effective explaining and thereby learning.

In sum, both spontaneous and prompted or trained self-explaining is associated with deep learning gains across a variety of domains, age ranges, and learning contexts. Several studies demonstrate that even when explicitly trained, however, the use of quality self-explanation remains variable indicating that it is difficult for some learners to engage in this activity. Furthermore, there is evidence that some learners may require scaffolding that goes beyond prompting or training in self-explanation to help them engage in this generative activity. It is possible that some learning contexts may be better suited to self-explaining than others. For example, mulitimedia environments may be more effective than single media environments for supporting this activity. In the following section, we explore this possibility.

Self-explanations in multimedia

In the preceding sections, we have discussed the overall effectiveness of self-explaining. Earlier, we also cited studies showing that in order to understand multimedia resources, learners must engage in the active processes of coordinating and integrating information across modalities and formats. Since there is more information to explain in multimedia materials compared to single media (i.e., there are within and between media relationships to be discovered), a constructive activity such as self-explaining might be especially suited to learning from resources such as text and illustrations. Below, we first provide a detailed example of an effective self-explaining episode in a multimedia learning situation to illustrate its potential role in fostering learning in a multimedia context. Second, we consider whether there is any evidence to suggest that self-explaining is particularly effective in a multimedia context. Third, we present analyses of the data from several existing studies that show that self-explaining is even more prevalent and more effective in multimedia than single media learning situations.

A multimedia example of self-explanation

As indicated above, one would likely find evidence of self-explanation in a situation where a learner is trying to understand an illustrated text. The following protocol excerpt from our own data provides such an example. It is taken from a study in which participants were asked to talk aloud as they were learning about the human visual system from a combination of text and a set of static schematic illustrations in a computer environment. The text and illustrations were available to the learner in separate windows and the learner was able to toggle between the two displays freely. In this excerpt the learner has just finished reading the sentence “The shape of the cornea is responsible for about 70% of the eye’s focusing power.”. Next, he generates the following question.

> SFI01: “So I’m wondering what’s the other 30 percent?”

After generating his question, he toggles to view an illustration showing a cross section of the eye that depicts and labels the various parts (including the cornea and the lens) as well as showing the shape of light energy as it passes through each of the structures. Now, he makes the following utterances.

> SFI01: “Ok so now I understand.
>
> I always thought that there’s just the lens and that the cornea and the

lens were the same thing.

But now I realize that it's the lens actually does the rest of the work.

I thought it was all the cornea or all the lens cause I though it was the same thing.

Ok I'm actually learning something."

There are several points of interest to be noted in this example. First, this learner demonstrates evidence of metacognitive knowledge monitoring in several utterances (e.g. "I'm wondering what's the other 30 percent?", " now I understand", "now I realize", and "I'm actually learning"). In addition, he demonstrates evidence of accessing prior knowledge and comparing his flawed understanding to new information in the learning materials (e.g., "I always thought that there's just the lens and that the cornea and the lens were the same thing.", and "I thought it was all the cornea or all the lens cause I though it was the same thing."). This series of events in turn gives him an opportunity to revise and repair his incorrect mental model (i.e., failing to distinguish between the cornea and the lens). Finally, the learner makes the correct inference that "the lens does the *rest of the work*" (i.e., of refracting light energy) resulting in new knowledge. Interestingly, this inference was made by integrating information across media. Specifically, it is based in part on his understanding of the text description that was previously read ("The shape of the cornea is responsible for about 70% of the eye's focusing power") in conjunction with his understanding of an illustration identifying the cornea and lens as separate structures and showing how the shape and trajectory of light energy changes as it passes through these structures. Although this process is actually described later in the text, this particular learner has not yet seen or read that section—but he has accurately predicted it.

The above example demonstrates that multimedia learning situations can provide a rich context for stimulating and supporting the different psychological mechanisms that have been proposed to underlie the self-explanation principle: the generation of learner-initiated inferences and the monitoring and repair of knowledge. In fact, we have already pointed out that in order to learn effectively from multimedia descriptions, learners must engage in knowledge construction activities. Self-explaining seems to be an ideal candidate.

Evidence of self-explanations in multimedia resources

Do multimedia environments lend themselves to the use of self-explanation more readily than single media resources? While there are no existing studies that directly compare self-explaining in multimedia to single media learning contexts, many of the studies reviewed earlier actually involve learning from multiple media (e.g., Aleven & Koedinger, 2002; Chi et al., 1989; Fergusson-Hessler & de Jong, 1990; Mayer et al., 2003; Renkl, 1997; Wong et al., 2002). Thus, there is evidence that learning in multimedia environments does benefit from self-explaining.

Moreover, there are a few studies that show more directly that self-explaining can help learners to integrate information across media, one of the aspects of learning from multimedia that may be difficult for learners. For example, Neuman and Schwartz (2000) performed a case study of six students solving multiple algebra problems while thinking aloud. The problems require that the student translate a text description (word problem) into a tabular array of relevant variables and quantities, then translate this representation into an appropriate algebraic form to be solved. Their analysis of learner protocols revealed that a particular type of self-explanation (categorical explanations) was associated with successful translation between the text and tabular representations.

A study by Aleven and Koedinger (2002) showed that prompting learners to generate self-explanations specifically helped students develop declarative knowledge that integrated verbal and visual information. In two classroom studies comparing the performance of a prompted self-explanation group (in which students were asked to explain in their own words the principle involved in each solution step used) to the performance of an unprompted group in a computer-based tutoring environment for learning geometry, they found that the prompted group was more successful on transfer problems and was better able to explain solution steps. The pattern of group differences on transfer problems correlated with different mathematical models of hypothesized internal knowledge constituents, thus suggesting that the best fitting model was a declarative knowledge model which integrated verbal and visual knowledge.

Finally, using Palinscar and Brown's (1984) reciprocal teaching technique, a technique that supports many of the same processes as self-explaining, Scevak, Moore and Kirby (1993) also found positive learning effects when the students were encouraged to more deeply process and relate text and map information. Thus, these three studies, taken together, provide some evidence that self-explaining can help learners integrate cross-modal information in multimedia situations. However, again, we cannot confidently conclude that self-explaining is in fact more effective in a multimedia versus a single medium context.

Is there any evidence to suggest that self-explaining is even more necessary and useful in different media contexts? Some have claimed that diagrams can be effective at encouraging high level processing like self-explanation (Brna, Cox, & Good 2001; Cox, 1999; Winn, 1991) because diagrams may provide computational offloading – freeing up cognitive resources for engaging in high level cognitive operations such as generating verbal self-explanations. It is also asserted that the low expressivity of graphics (when compared to text) may assist learners to more accurately reflect on their understanding and constrain their self-explaining to fit within a specific explicit context. In addition, we offer a contrasting hypothesis, that instead of constraining learners' interpretation, the low expressivity of graphics and diagrams may actually necessitate more self-explaining in order to fill in and elaborate the information that is absent from such illustrations.

A recent study comparing the self-explanation effect across two different single media situations--text and diagrams, has provided the first direct evidence that diagrams are better than text at eliciting more and better quality self-explanations from learners (Ainsworth & Loizou, 2003). These researchers compared the self-explanation effect in a text-only condition with an informationally matched diagrams-only condition in the domain of biology. They found that students given diagrams performed significantly better on post-test, independently of the effects of time on task, pre-test score, and amount of talk generated. Furthermore, the diagram students generated more self-explanations, particularly goal driven explanations in which they described the purpose of an action. Finally, they found that the benefits of self-explanation were greater in the diagram condition, i.e., the correlation between self-explanations and knowledge gains was only significant within this group.

The results of Ainsworth and Loizou clearly indicate that the medium of instructional material can influence the amount of quality self-explanations and associated gains among learners. However, while the researchers offer a variety of reasons as to why this might be the case, it is not clear which of these possibilities is supported. Furthermore, the question of what the combined effects of such media (e.g., text and diagrams) would be on self-explanation remains an open one.

Comparing results across information formats

Do multimedia environments lend themselves to the use of self-explanation more readily than single media resources? If so, we would expect to see more frequent use of high quality self-explaining and larger associated learning gains for self-explanation studies that use multimedia rather than single media learning materials. Table 1 below presents a summary of data reporting the amount of quality self-explanations for learning contexts with different information formats (i.e., multimedia, text only, and diagrams only).

A brief explanation of how the presented numbers were calculated is in order. Obviously, only studies that report data on the frequencies of their codings of verbal protocols could be included. Second, all codes which fall under the description of inferencing, prior knowledge access and/or use, self-monitoring, and metacognition were pooled together as estimates of the frequency of self-explanation. Third, the pooled frequencies estimates have been converted to percentages (i.e., self-explanation statements relative to total statements which include other types of statements like paraphrases) to enable fair comparison across studies. Finally, the amounts for studies which report separate numbers for “High” versus “Low” explainers (Chi et al., 1994), “High” versus “Low” learners (Chi et al., 1989; Fergusson-Hessler & de Jong, 1990), “Prompted” versus “Un-prompted” explainers (Hausmann & Chi, 2002), or “Trained” versus “Untrained” explainers (McNamara, in press; Wong et al., 2002) were pooled across their comparison categories to yield average estimates. Average estimates are reported for each learning context. Also, the average estimate for the text-only context is reported both with and without the data from Hausmann and Chi (2003). That study required learners to type their self-explanations which appears to have seriously hampered the frequency of self-explanations generated.

The resulting percentages indicate that the frequency of self-explanation is lowest in text-only situations and substantially higher in multimedia situations, as predicted. This pattern provides some support for the hypothesis that multimedia situations are better at stimulating and supporting self-explaining than text-only learning situations. Not surprisingly, the amount of self-explanation was highest for the diagrams-only condition. This supports our hypothesis that the low expressivity and sketchiness of illustrations and diagrams may necessitate a greater amount of self-explaining in order for the learners to construct a coherent understanding.

Table 1. Percent of Self-explanation for Different Learning Contexts.

Study	Text	Multimedia	Diagrams
Ainsworth & Loizou (2003)	57.69%		91.61%
Chi et al (1989)		63.00%	
Chi et al (1994)	58.00%		
Hausmann & Chi (2002)	8.45%		
Fergusson-Hessler & de Jong (1990)		72.00%	
McNamara (in press)	19.43%		
Wong et al. (2002)		69.80%	
Average Estimate	35.89% 45.04%*	68.26%	91.61%

* Excludes the results of Hausmann & Chi (2002) which may seriously underestimate the amount of orally generated self-explanations supported in text learning environments.

In addition to comparing the percentage of self-explaining activity across different learning contexts, we were also interested in comparing associated learning outcomes. If multimedia environments are better at supporting the generation of quality self-explanations than single media, we should see an associated difference in the size of learning gains observed. That is, pre to posttest gains should be higher in multimedia contexts. Table 2a below presents estimates of learning gains from pretest to posttest for self-explanation studies across different learning contexts. The results of table 2a indicate that the overall average gain in learning is roughly equal for text and multimedia learning context but that the gain for diagrams-only context is substantially higher. However, the gain (21.86%) of the text only condition may be overestimated, since the learning measures in the text-only studies reported above tend to be or include shallow measures of learning (e.g., vocabulary, verbatim questions, text-based questions), whereas the

Table 2a. Learning Gains for Self-explanations in Different Learning Contexts.

Study	Text	Multimedia	Diagrams
Ainsworth & Loizou (2003)			
Unprompted self-explaining			
Text/Illust-based Questions (gain)	18.00%		45.00%
Diagram of blood path (gain)	11.11%		42.22%
Chi et al (1994)			
Verbatim & Inference Questions (gain)			
Prompted self-explaining (gain)	32.00%		
Unprompted self-explaining (gain)	22.00%		
Hausmann & Chi (2002)			
Vocabulary			
Unprompted self-explaining (gain)	24.8%		
Control (gain)	23.4%		
Renkl (1997)			
Unprompted self-explaining			
Total Problem-solving (gain)		47.33%	
Wong et al. (2002)			
Total Problem-solving (gain)			
Trained (gain)		13.68%	
Control (gain)		-00.09%	
Average Overall Gains (pooled across groups)	21.86%	20.37%	43.16%

multimedia studies in table 2a report deep learning gains (e.g., problem-solving performance). In particular, the results of the Wong et al (2002) study includes far transfer problem-solving items.

Because many studies do not use pre-posttest designs or report additional performance data at posttest only (e.g., transfer data), in order to get a larger sample, Table 2b presents observed post performance outcomes for the different groups within each study (e.g., “High” versus “Low” learners , “Prompted” versus “Un-prompted” explainers, and “Trained” versus “Untrained” explainers) for the different types of learning context. As predicted, the overall average performance (i.e., pooled across groups) was larger for explainers in the multimedia situation compared to the text-only situation. Again, this difference is probably somewhat conservative in that several of the text-only studies reported in table 2b include shallow indices of performance of learning (e.g., vocabulary, verbatim questions, text-based questions), whereas the whereas the multimedia studies report deep learning performance (e.g., transfer). The trend of greater learning from text to multimedia to diagrams, corresponds to the increasing trend of greater amount of self-explaining from text to multimedia to diagram.

Similar to the data regarding the frequency of self-explaining, we see that the diagrams-only condition produced even higher gains than the multimedia condition. This outcome is consistent with our hypothesis suggesting that the diagrams-only condition is even less constraining than learning in a multimedia environment and is therefore a more effective context for eliciting self-explaining. That is, because there is typically more information for learners to fill in or generate in learning from diagrams, learners are more active and simply generate more self-explanations resulting in deeper learning. While further research is required to substantiate this pattern, these data do suggest that multimedia environments are more effective then text at stimulating and supporting quality self-explaining.

Taken together the results of tables 1, 2a, and 2b indicate that self-explaining is more prevalent in multimedia than in text environments, and that the associated benefits for those who tend to self-explain a lot is larger in multimedia environments than in text only situations. This pattern of results indicates that engaging in deep constructive activity like self-explanation is even more necessary for effectively learning in multimedia than single media contexts.

Table 2b. Post Performance for Self-explanation in Different Learning Contexts.

Study	Text	Multimedia	Diagrams
Ainsworth & Loizou (2003)			
Unprompted self-explaining (post)			
Implicit Questions	49.17%		61.67%
Knowledge Inference	46.67%		78.33%
Chi et al (1989)			
Near Transfer			
High learners (post)		96.00%	
Low learners (post)		62.00%	
Far Transfer			
High learners (post)		68.00%	
Low learners (post)		30.00%	
Hausmann & Chi (2002)			
Verbatim questions	61.7%		
Unprompted self-explaining (post)	60.0%		
Control (post)	1.70%		
Integration questions			
Unprompted self-explaining (post)	31.2%		
Control (post)	38.4%		
McNamara (in press)			
Text-based questions			
Trained (post)	56.75		
Control Group Performance(post)	43.95		
Bridging questions			
Trained Performance	31.95		
Control Group Performance	25.35		
Wong et al. (2002)			
Near Transfer			
Trained (post)		86.06	
Control (post)		78.23	
Far Transfer			
Trained (post)		59.84	
Control (post)		42.28	
Average Overall (pooled across groups)	44.51%	52.54%	70.00%

Instructional Design Implications

How should multimedia environments be designed so that they effectively encourage and support the generation of quality self-explanations? As we noted earlier, many studies demonstrate that students learn better from a combination of media providing that the materials are designed with some important properties of the human cognitive system in mind.

It is clear that the use of self-explanation strategies takes up substantial cognitive resources. In fact, it has been suggested by various researchers that if the learning material itself imposes a heavy cognitive load then learners may not be able to engage in such resource demanding activity (Chandler & Sweller, 1991; Mayer ,1997; Mayer, Heiser, Lonn, 2001; Mayer, Dow, & Mayer, 2003). One explanation for poor learning outcomes in such environments is that the learner's opportunity to engage in self-explanation is hampered. Thus, when designing multimedia environments that will support self-explanation, one ought to try and minimize placing undue cognitive load on the learner by presenting related text and diagrams closely; by minimizing the use of unrelated information, and by avoiding the duplication of messages across two different modalities that use the same information processing channel (e.g., text and narration).

Second, the environment should assist learners to think "inwardly" and "reflectively". Specifically, it should encourage learners to bring their prior knowledge to bear on the interpretation of materials and allow them to monitor and test their evolving understanding. Presenting the target domain in multiple related external representational formats should increase the probability of activating relevant prior knowledge from the learners leading to increased opportunities to relate new information to prior knowledge.

Third, a good multimedia learning environment should encourage the generation of new inferences in which the learner relates information within and between media and to relate this to her prior knowledge. As argued at the outset of this chapter, multimedia learning situations can provide a rich context for eliciting and supporting quality inferences by providing complementary information. Such resources have the potential to be more structured and constraining than single media contexts. For example, illustrations, being an external model of the discourse situation, can serve as a particular context in which to interpret and reason about the text (i.e., to self-explain about the text content and how that may relate to the content depicted in one or more illustration(s) as well as to what learners already know). As such, the presence of illustrations in the context of text should constrain what information the learner integrates within the text, between text and illustrations, and between the newly derived knowledge with the learner's prior knowledge. Such constraints might facilitate the generation of more relevant and deeper self-explanations.

Another instructional design concern has to do with the mode of expressing self-explanations. Hausmann and Chi (2002) found that the amount of self-explanation that learners generated in a computer environment was suppressed by having learners type rather than verbalize their thoughts. Thus, modality of expression matters. Supporting alternative and multiple media to express self-explanations may generate more sensitive measures of what learners understand and are able to make sense of (Crowder, 1996; Koschmann & LeBaron, 2002). It is possible that generating diagrams as a part of verbal self-explanation may be useful. By restricting learners to adopt a linguistic modality some inadequacy of their current interpretations of materials may be concealed or go unnoticed. It may well be that constructing an external representation in an alternative modality may have a significant effect on learning (Cox, 1999). Indeed, Chi et al. (1994) found that students who were high-self explainers also drew more diagrams.

Furthermore, it is possible that prompting students to explain their self-generated diagrams would be beneficial. This position is supported by a study carried out by Van

Meter (2001) examining the use of drawing as a learning strategy for 5th and 6th graders reading a science text. She found that students who were prompted to compare their own drawings to a provided illustration (similar to prompted self-explanation) learned more effectively than unprompted students, students who were simply encouraged to create drawings, or a no drawing control group. Furthermore, all drawing groups learned more than the control group and engaged in significantly more self-monitoring while reading.

Finally, multimedia environments could be designed to scaffold self-explanations for learners at different levels of skill acquisition (e.g., Conati & VanLehn, 2000) or who are very young or novice (e.g., Siegler, 2002) thereby supporting a greater variety of learners.

Discussion

Meaningful learning in multimedia environments requires learners to construct coherent integrated representations. The existing self-explanation literature supports the assertion that learning from multimedia environments is substantially improved when learners engage in deep knowledge construction and integration activities, like those involved in self-explaining.

It is also true, however, that deep understanding does not come easy. The activity of self-explaining is itself cognitively demanding and there is consistent evidence that many learners have difficulty engaging in generating a sustained level of quality explanations. We have reviewed the self-explanation literature with an eye for suggesting that many learners would benefit from self-explanation training or prompting within multimedia environments. Essentially, we have argued that because they are informationally rich, multimedia environments afford the generation of many opportunities for explaining encoded information and accessing and relating prior knowledge. Furthermore, because there are additional relationships between media, multimedia situations are somewhat more constrained (certainly more constrained than diagrams or illustrations), and should facilitate the integration of information and the generation of certain inferences, particularly for low prior knowledge learners. Again, the self-explanation literature appears to support this assertion.

While we found only one study that focuses directly on the effects of diagrams on self-explaining and learning, there seems to be a trend in the literature indicating that self-explanation effects are smallest in text context, greatest in diagram context, and intermediate in multimedia context. This pattern seems to suggest that the more information learners must (and can) fill in to make sense of the materials, the greater the effect of self-explanation.

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Glossary

Self-explanation principle: The self-explanation principle refers to the finding that people learn more deeply when they spontaneously engage in or are prompted to provide explanations during learning.