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Promoting vicarious learning of physics using deep questions with explanations

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A B S T R A C T

Two experiments explored the role of vicarious “self” explanations in facilitating student learning gains during computer-presented instruction. In Exp. 1, college students with low or high knowledge on Newton’s laws were tested in four conditions: (a) monologue (M), (b) questions (Q), (c) explanation (E), and (d) question + explanation (Q + E). Those with low pre-experimental knowledge levels showed marginally significant yet consistently greater gains than those with high levels and condition Q + E outperformed the other three (M, Q, E). Among those with high knowledge, the Q + E presentations actually inhibited learning. In Exp. 2, high school physics students in standard and honors classes were studied during their introduction to Newton’s laws. Brief (12 min) computer videos that introduced key Newtonian concepts preceded teacher presentations in seven daily sessions. Both standard and honors students who received Q + E presentations prior to regular classroom activities learned more in daily sessions than those who received either M or Q presentations. It was concluded that when key concepts are introduced in the context of deep questions along with explanations new learning was facilitated both in vicarious environments and in subsequent standard classroom activities.

1. Introduction

During the past decade research supporting the conclusion that, when contrasted with various comparison conditions, vicarious exposure (Bandura, 1962, 1977; Rosenthal & Zimmerman, 1978) to computerized presentations of curriculum content in the context of deep-level reasoning questions (henceforth *deep questions*) leads to significant increases in knowledge acquisition among students in middle school (Craig et al., 2008), high school (Craig, Brittingham, Williams, Cheney, & Gholson, 2009), and college (Gholson, Coles, & Craig, 2010). Deep questions, which are designed to encourage thoughtful integrative explanations, include stems such as “How does the…?’, “Why is the…?” and “What happens when…?” (Bloom, 1956, 1977; Gholson & Craig, 2006; Graesser, Baggett, & Williams, 1996; Graesser, Franceschetti, Gholson, & Craig, 2011; Graesser & Person, 1994; Rosenshine, Meister, & Chapman, 1996). These stems may be contrasted with shallow level questions, such as “Which is the…?”, “What is the…?”, and “Does X include…?”, that usually suggest one-word answers (Driscoll et al., 2003; Graesser & Person, 1994). Developments in this research domain have been reviewed elsewhere (Gholson et al., 2010; Gholson & Craig, 2006), so we will only highlight a few findings here.

In a preliminary study, Craig, Gholson, Ventura, Graesser, and The Tutoring Research Group (2000) found that college students, who listened to a dialog in which two virtual agents located on a monitor discussed course content, learned more when they overheard each content statement introduced into a dialog by a deep question than when they overheard discussion of the content that did not include deep questions. Driscoll et al. (2003), Craig, Driscoll, and Gholson (2004), McKendree, Good, and Lee, (2001) and Sweller (1999) then showed that neither overhearing discussions of content in the context of shallow questions, nor discussions involving concept repetition, led college students to the same high level of enhanced learning as introducing each new content statement with a deep question.

A subsequent series of studies (Craig, Sullins, Witherspoon, & Gholson, 2006; Gholson, Witherspoon, Morgan, Brittingham, Coles, Graesser, Sullins, & Craig, 2009; Craig, Gholson, & Driscoll, 2002) included conditions in which interactive tutoring sessions with an effective intelligent tutoring system, called “AutoTutor” (Graesser et al., 2011; Graesser & Olde, 2003; Graesser, Person, Harter, & The Tutoring Research Group, 2001; Graesser, Wiemer-Hastings, Wiemer-Hastings, Harter, Person, & The Tutoring Research Group, 2000; VanLehn et al., 2007), were contrasted with vicarious conditions. In the first (Craig et al., 2006, Exp. 1), college students in an *interactive*

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tutoring condition were contrasted with four computer-presented vicarious conditions. A *yoked vicarious* condition involved presenting each learner with a recorded session taken from the interactive tutoring condition. In a *content-only* vicarious condition learners were presented with two sentences taken from AutoTutor's curriculum script concerning each concept used in the interactive tutoring condition. In a third, *half questions* vicarious condition, learners received one of the two sentences concerning each concept in AutoTutor's script that were used in the *content-only* condition, each preceded by a deep question. In the final, *full questions* vicarious condition, a deep question was presented prior to each of the sentences used in the *content-only* condition.

Learners in the *full questions* vicarious condition significantly outperformed (learned more) those in each of the remaining four conditions, including *interactive tutoring*. Pretest-to-posttest learning gains in those four latter conditions were reasonably comparable (see Craig et al., 2006, Table 1). Because the impact of embedding deep questions in educational content may have important implications for those designing curricula for distance learning and for computerized learning environments in general, it was deemed necessary to replicate Exp. 1. The findings did completely replicate, college students in two vicarious deep questions conditions both significantly outperformed those in interactive tutoring and another vicarious condition (Craig et al., 2006, Exp. 2).

More recently younger students, 8*th*, 9*th*, 10*th*, and 11*th* graders, were studied (Gholson, Witherspoon, et al., 2009). Experimental conditions at each grade level included (a) *interactive tutoring* sessions with AutoTutor, that were contrasted with two vicarious learning conditions presenting (b) *content-only* sentences taken from AutoTutor's curriculum scripts, and (c) the same content sentences each preceded by a *deep question*. Based upon prior research with college students, we predicted that younger vicarious learners presented course content containing deep questions would exhibit greater learning gains than those in both the interactive tutoring and content-only conditions. Eighth and tenth graders learned computer literacy, while ninth and eleventh graders learned Newtonian physics.

Pretest-to-posttest gains were used to assess learning. There were no significant differences at pretest among the three experimental groups at any grade level or among grade levels. Gain scores yielded only significant main effects. The difference of interest here was the effect of experimental condition (learning gains in favor of the older students and in the physics domain were also obtained). Those in the deep questions condition showed significantly greater gains (about twice as large) than those in both the interactive tutoring and content-only conditions, which did not differ from each other. Although previously shown only among college students in the domain of computer literacy, in the Gholson, Witherspoon, et al. (2009) study the deep question effect was also shown to hold in the domain of Newtonian physics as well as computer literacy among eighth to eleventh graders.

We recently borrowed the term "catalyst" from chemistry to refer to the impact of deep questions in uniting disparate sources of information in memory and providing a context for integrating new content into coherent, logical, and/or causal reasoning chains during vicarious learning (Gholson, Craig, Brittingham, Germany, Fike, & Cheney, 2009). Thus, each deep question functions as a *knowledge catalyst*. Most catalytic agents bind with reactants during the steps in the chemical reactions that lead to the final product, but in the final step the catalytic agent is released from that final product and regenerated. Technically, the deep questions may function as *stoichiometric catalysts*, because in uniting the previously separate chemical elements (disparate knowledge sources in memory) copious amounts of this catalytic agent (causal structure in deep question, see above) may be completely consumed and become an integral part of the resulting chemical compound (new causally integrated knowledge structure). We will, however, adopt the more parsimonious term, knowledge catalyst.

The findings described above led us to consider *other* candidate features of vicarious environments that might also function as knowledge catalysts. One such potentially powerful manipulation that has not been explored in vicarious environments involves self explanations (Ainsworth & Burcham, 2007; Chi, 2000; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, Roy, & Hausmann, 2008). When learners overtly explained a concept immediately after it was presented, usually by integrating it with existing knowledge (Chi, 2000), those *self explanations* produced large learning gains when compared to various controls (Chi et al., 1989). Self explanations are clearly distinguished from other sorts of verbal commentary, such as paraphrase or self monitoring statements (Ainsworth & Loizou, 2003; Chi, Siler, Jeons, Yamauchi, & Hausmann, 2001). They embed new content in a web of existing knowledge. As described by Chi et al. (2008), then, self explanations may, like deep questions, function as knowledge catalysts, encouraging cognitive activities that unite desperate sources of information in memory that expose knowledge gaps and provide a coherent causal context for integrating new content. Research reported below explored whether *overheard* (vicarious) analogs of self explanations, might, like deep questions, serve as knowledge catalysts that increase learning gains, first among college students in the laboratory (Exp. 1) and then among younger students studied individually in the classroom (Exp. 2).

2. Experiment 1

Unfortunately, students do not spontaneously generate self explanations at high rates, In fact, even when students are prompted, only a small proportion of their verbalizations are genuine self explanations. Instead students mostly verbalize self monitoring statements or paraphrase recently-presented content (Chi, 2000; Chi, de Leew, Chiu, & LaVancher, 1994). In fact, even when prompted about half of the students tested by Chi et al. (1994) failed to generate self explanations during an intensive study spanning as many as three or four daily sessions. While the students who generated explanations showed improved mental models and dramatic learning gains, those who failed to generate self explanations did not develop adequate mental models, and they performed at the same level as a comparison group who

Table 1
Pre and posttest scores for each experimental condition and knowledge level.

	Combined						Low knowledge						High knowledge					
	Pretest		Posttest		Change		Pretest		Posttest		Change		Pretest		Posttest		Change	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
M	.31	.11	.52	.15	.21	.15	.22	.07	.45	.15	.23	.15	.40	.05	.59	.13	.19	.15
Q	.31	.10	.52	.17	.21	.16	.25	.06	.45	.15	.21	.17	.42	.06	.63	.13	.21	.15
E	.31	.11	.53	.17	.22	.19	.24	.05	.51	.19	.26	.18	.43	.08	.57	.15	.15	.19
Q + E	.36	.16	.52	.16	.16	.20	.22	.08	.53	.13	.31	.09	.45	.12	.52	.18	.07	.20