Television, Games, and Mathematics:
Effects of Children's Interactions with Multiple Media

Abstract

Past research has shown that educational media, such as a television series or interactive games, can promote significant learning. Today, however, it is quite common for producers to create several interconnected media, such as a television show and an associated web site, under the assumption that multiple platforms elicit greater learning than a single medium would. The research reported below used *Cyberchase* media as the setting in which to investigate the effectiveness of multiple media as a tool for mathematical learning for elementary school children. The study included both a naturalistic phase, which mirrored children's typical use of the media, and an experimental phase, which allows for causal inference to be drawn about their learning outcomes.

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Introduction

Children's love for good stories and for playing games lie at the heart of our interest in exploring what makes interactions with electronic storytelling and online game play not only entertaining but also educational. Even before children start school, children interact with all sorts of electronic media. Research reports that children 6 months through 6 years of age spend an average of 2 hours daily with screen media, and that 50 percent of 4-6 year olds play regularly with computer games (Rideout et al., 2003). The ubiquity of media in children's lives has given rise to concerns over the potential contributions of electronic media to negative outcomes, such as obesity or violent behavior (e.g., American Academy of Pediatrics, 2001; 2009). For many years, critics have doubted whether even positive, educational media can succeed in promoting learning, suggesting that the very nature of television and computers impairs attention spans and deep thinking (e.g., Healy, 1990, 1998; Postman, 1985). However, both theoretical analyses (e.g., Gee, 2003) and the empirical research literature (e.g., Fisch, 2004, 2009) have proven these critics wrong. Research shows that children do learn from their use of well-designed educational television programs and interactive computer games.

Yet, even this body of research does not tell the whole story. Amid industry buzzwords such as "multiple platforms" and "transmedia," it is increasingly common for projects to span several media platforms, such as a television series, Web site, hands-on outreach materials, museum exhibit, and live stage show. From an educational standpoint, producers assume this combination of media yields added benefits for children's learning, beyond those that might be provided by one medium alone. But is this assumption true? Past research has focused almost entirely on the impact of one media component, such as a television series or a computer game in isolation. This leaves open the question of whether greater learning might emerge from using a group of components that span multiple platforms (which we shall refer to as *cross-platform learning*).

Theoretical Background

Our study of children's cross-platform learning is grounded in the theoretical and empirical literature on *transfer of learning* – students' ability to apply concepts or skills acquired in one context to a new problem or context. The literature has documented many different types of transfer of learning (for example Haskell [2001] distinguished among 14 types of transfer), and numerous theoretical mechanisms have been offered to explain how and why they occur (e.g., Gentner, 1983; Greeno, Moore, & Smith, 1993; Holyoak, 1985; Salomon & Perkins, 1989; Schwartz, Bransford, & Sears, 2005).

Particularly relevant to our research is the principle, adopted by several existing theories, that transfer can be elicited through *varied practice* (i.e., providing learners with multiple examples of the same concept or repeated practice of a skill in multiple contexts). Varied practice helps learners create a generalized mental representation of the material that is less context dependent, and more easily applied to new tasks and situations (e.g., Gick & Holyoak, 1983; Salomon & Perkins, 1989; Singley & Anderson, 1989). For informal education, we hypothesize that encountering similar content (e.g., a mathematical concept or problem-solving heuristic) in multiple contexts and media would lead, not only to a better grasp of the content, but also a greater likelihood of transfer to new problems as well.

Apart from the potential for varied practice to contribute to learning, research suggests that repeated, varied engagement with mathematical content can also promote positive attitudes toward mathematics (e.g., interest, motivation). Several theoretical approaches argue that interest in an academic subject develops from repeated, positive engagement with its content – for example, from repeated practice that results in positive emotional outcomes, from seeing the broader applicability and usefulness of the content, or from internalizing interest via encountering the content in engaging situations (e.g., Bransford, Brown, & Cocking, 1999; Hoffman, Krapp, & Renninger, 1998).

Indeed, even the literature on attitude change in the context of advertising indicates that positive attitudes are more likely to occur from repeated exposure to persuasive messages – particularly if the precise content of the messages is somewhat varied (e.g., Kunkel, 2001; Petty, Priester, & Briñol, 2002). Under Hidi and Renninger's (2006) four-phase model of interest development, interest in an academic subject such as mathematics originates as interest sparked by the context in which the math is embedded (in this case, a math-based educational television program or game), and can evolve over time into interest in the underlying mathematics itself. In the domain of informal education, then, we hypothesize that experiencing math content via engaging materials across multiple media platforms contributes to the development of greater interest and positive attitudes toward mathematics.

Research Design

To investigate the effects of multiple media this study focused on one such example for informal mathematics education, *Cyberchase*. Produced by Thirteen/WNET, *Cyberchase* is a popular and successful multiple-media mathematics project, targeted at children aged 8 through 11, that includes the following components:

- *Television series.* The animated *Cyberchase* series airs daily on PBS Kids Go! *Cyberchase* features three diverse youngsters who are summoned into Cyberspace to foil the dastardly Hacker. Each half-hour episode sends the team on a mystery based on a mathematics concept. Through their adventures, the series models mathematical reasoning, problem solving, and positive attitudes toward mathematics. Its underlying themes are that mathematics is everywhere and is infinitely useful. Nearly three million viewers – 43% of them African-American or Hispanic – tune in each week.

- *Web site. Cyberchase Online (www.pbskids.org/cyberchase)* complements the series with interactive games and puzzles, based on the same mathematical content as the television series. The site receives 1.8 million visits from nearly 700,000 unique visitors per month.

- *Hands On materials. Cyberchase* outreach engages children in hands-on math activities based on the television programs. Facilitators use a wide inventory of print and multimedia materials, including activity guides with DVDs of related episodes, for use in programs with children and workshops with colleagues. Partnerships with organizations such as Girls Inc. and the National Society of Professional Engineers bring *Cyberchase* outreach activities to communities nationwide, with a focus on girls and under-served children.

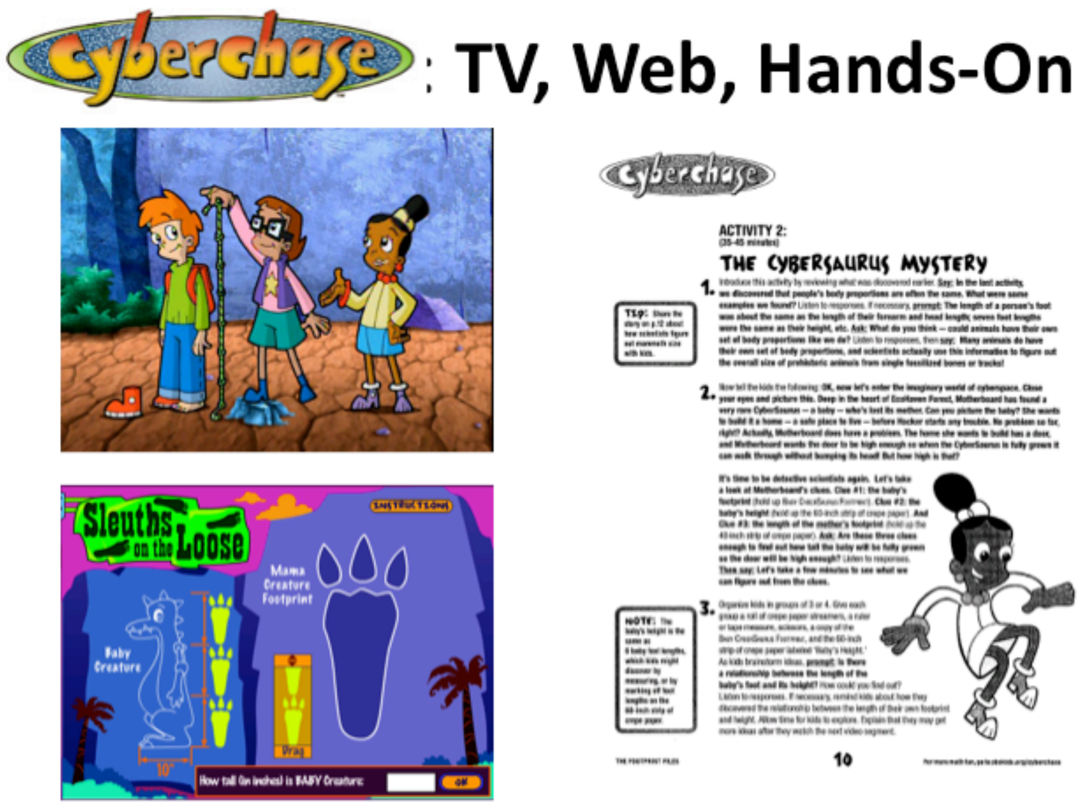


Figure 1. Sample of multiple *Cyberchase* media —TV, web, and hands on materials

This wealth of resources made *Cyberchase* well-suited to explore our questions regarding the effects of interacting with mathematics via multiple media. In our project and in this paper in particular we use *Cyberchase* as the context in which to address the following research questions.

1) What learning outcomes (including attitudinal outcomes) derive from children's engagement with different types and combinations of electronic media?
2) What is the relative contribution of each type of media on children's learning outcomes?

<u>*Research Participants*</u>

Participants were 672 children in nine public elementary schools in Michigan and Indiana. All of the children transitioned from third to fourth grade during the naturalistic phase, and remained in fourth grade during the experimental phase. (The phases of the project are described below.) Essentially the same sample of children participated in both the naturalistic and experimental phases of the research, apart from some natural attrition as children moved into or out of their communities between third and fourth grade.

The sample was fairly evenly divided in terms of gender (52% girls, 48% boys), mathematics ability (31% high, 42% medium, 27% low), and whether math had been their favorite school subject prior to the study (43% yes, 57% no). Approximately 30% of the sample was comprised of minority children (17% African-American, 6% Latino, 4% Asian, 3% other).

Several schools were not willing to release socio-economic (SES) information regarding individual children. However, we were able to obtain aggregated statistics regarding eligibility for free or reduced lunch for each school as a whole. On average, 35% of the students at the participating schools were eligible for free or reduced lunch.

<u>*Research Phases*</u>
One key consideration in the design of any research study is whether to adopt a naturalistic approach, which allows more direct comparison with real-world use, or an experimental approach that provides a greater degree of control and allows researchers to attribute causality among the variables measured. In this study we took advantage of both approaches. First, we conducted a *naturalistic phase*, whose primary purpose was to gauge children's naturalistic use of various *Cyberchase* media, and ways in which use of one medium feeds into another. This phase was followed by an *experimental phase*, in which treatment groups were exposed to various combinations of *Cyberchase* media. In this way, the design of the proposed research combined the power of experimental methods to yield clear, unambiguous evidence of effects with the real-world "meaningfulness" of naturalistic data.

The following table summarizes the schedule under which the study was run.

Schedule	**Activities**
April-June (start and end dates staggered to fit school schedules)	Background measures Assessment: Naturalistic phase pretest Naturalistic phase, part 1: approximately 6 weeks
October-December (start and end dates staggered to fit school schedules)	Naturalistic phase, part 2: approximately 6 weeks Assessment: Naturalistic phase posttest/Experimental phase pretest
January-March (start and end dates staggered to fit school schedules)	Experimental phase: 8-week treatment period Assessment: Experimental phase posttest *Cyberchase* interviews with teachers and children

Naturalistic Phase: During this phase of the study the children in the study kept a user journal in which they reported their viewing and playing information and also were administered a suite of surveys related to their mathematical attitudes and mathematical performance.

Measures administered during the naturalistic phase included:

- *Background questionnaire:* Administered at the beginning of the naturalistic phase, this measure gathered data on children's demographics (e.g., age, gender), prior viewing of *Cyberchase*, *Liberty's Kids*, *Scooby-Doo*, and *SpongeBob Squarepants*, as well as prior use of their related Web sites. A parallel measure was administered at the beginning of the fall data collection, to gather information about their use of *Cyberchase* and *SpongeBob Squarepants* during the summer.
- *Cyberchase journal:* Administered once each week, children used the journal to record their self-selected, voluntary use of the *Cyberchase* television series and Web site: whether (and on which days) they used each, how much time they spent on the Web site, and what activities they did on the Web site. For comparison, they answered the same questions about *SpongeBob Squarepants* and its Web site.

In addition, several pencil-and-paper measures of mathematical problem solving (pretest-posttest) and attitudes toward mathematics (posttest only) were also administered. These are described in detail in the discussion of the experimental phase below.

Apart from the information obtained directly from children via the above measures, we also collected teacher ratings of each child's mathematics ability (high/medium/low) and information regarding ethnicity and SES through the participating schools.

Experimental Phase: Whereas the purpose of the naturalistic phase was primarily to explore and document patterns of media use regarding *Cyberchase*, the experimental phase was focused on assessing impact regarding cross-platform learning. The experimental phase had three primary goals: (1) To establish causality in studying the impact of multiple media on children's mathematical problem solving and attitudes toward mathematics. (2) To assess how effects might differ as a function of children's exposure to different combinations of media components. (3) To determine the respective contributions of each media component, and how these contributions interact to yield cumulative effects.

To that end, the experimental phase employed an experimental/control, pretest/posttest design that allowed us to investigate the impact of various combinations of *Cyberchase* media on the growth of children's mathematical problem solving (and, secondarily, their attitudes toward mathematics).

Experimental treatment. Over the course of an eight-week treatment period, intact classrooms of children were assigned to one of the following five experimental groups:

- *DVD Only group:* Each week, children were shown three half-hour episodes of *Cyberchase* in school (a total of 24 episodes)
- *Web Only group:* Each week, children played a mathematics-based game on the *Cyberchase* Web site (a total of 8 games), but were not shown the TV series.

- *DVD + Web group:* Children were shown three episodes of *Cyberchase* per week. Once each week, they also played an online game whose mathematical content was (in most cases) aligned with at least one of the TV episodes they viewed.
- *All Materials group:* Children followed the same schedule as in the previous group. Once each week, they also engaged in a hands-on *Cyberchase* outreach activity that involved the same mathematical content as in one or more TV episodes (a total of 8 hands-on activities).
- *No Exposure (i.e., control) group:* Children were not exposed to any of the above materials. Instead, each week, they were shown three half-hour episodes of an age-appropriate series about American history (*Liberty's Kids*).

Measures. The following measures were administered during the experimental phase:

- Hands-on mathematical problem-solving tasks, with essentially isomorphic versions of each task administered in the pretest and posttest.
- Paper-and-pencil problem-solving tasks, administered in the pretest and posttest.
- Online tracking data that automatically recorded every click children made while playing three of the interactive games on the *Cyberchase* Web site. The tracking data lent insight into children's mathematical thinking while playing the games.
- Several paper-and-pencil measures of interest and confidence regarding various mathematical activities (administered in the pretest and posttest) and children's orientations toward pursuing challenges (posttest only).
- Finally, to help interpret these data, the posttest was followed by supplementary interviews with children (regarding their experience with *Cyberchase*) and teachers (to gather their perspective on children's learning from *Cyberchase*, as well as their own experiences with the materials).

Results

In this study we found that children's use of *Cyberchase* tended to span media; that is each month, children who watched the *Cyberchase* TV series more frequently also tended to visit its Web site more often. Thus, in naturalistic use, some children do indeed use multiple media when they are available (which lends real-world validity to the question of how children learn from multiple media). Because most of the participants' first encounter with *Cyberchase* occurred long before we began collecting data, the present data cannot determine which medium came first. However, past research has found that children more often begin by watching the TV series and subsequently expand to using the Web site as well (Fish, 2003). In our project we found that use of each form of *Cyberchase* media (TV and Web site) was fairly consistent over time. Those children who watched *Cyberchase* on TV in one month tended to do so in subsequent months as well. A similar pattern was found for month-to-month use of the Web site.

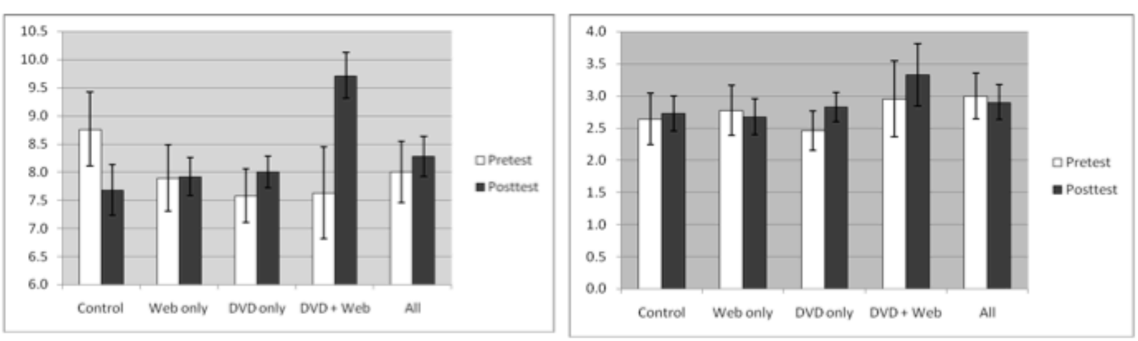
Past research (which evaluated the educational effects of the *Cyberchase* TV series alone) found evidence of significant impact on both the process of children's mathematical problem solving and the sophistication of their solutions (Fisch, 2003; 2004). The present study replicated that finding, and extended it by finding more consistent effects of video plus online games than of either medium alone (especially in comparison to online games alone).

Comparison across all of the experimental groups yielded many interesting results. As expected, children assigned to the experimental groups outperformed those in the control group, and that children who used both *Cyberchase* DVDs and online games showed greater gains in problem solving than children who used either medium by itself. Yet, although it seemed reasonable to expect that the more exposure to academic content via multiple media would yield the highest posttest gains, we found instead that more is not necessarily always better. Surprisingly, children in the *DVD + Web* group also showed consistently greater gains than children in the *All Materials* group (which used the same materials plus hands-on classroom activities). Figure 2 shows a pre-post comparison of all groups in one set of measures.

It is also worth noting that there were some cases (as in the second graph shown here) in which children who used the DVDs showed statistically significant gains but children who used only the online games did not, suggesting that children's gains in problem solving performance were driven more by the TV series than by the online games. In this study, we suspect that this is due to the fact that television is designed to serve as the central component of *Cyberchase*, and provides greater explanation of mathematical concepts than the games (which allow children opportunities to exercise skills, but present less overt explanation). Such explanation -- embedded in the context of appealing characters and a compelling narrative -- appeared to provide both the necessary understanding and modeling of processes and dispositions for effective problem solving (e.g., persistence, top-down planning). However, non-*Cyberchase* games designed for more overt instruction and explanation (e.g., via online agent characters who scaffold children's performance) might produce stronger effects of their own.

Paper-and-Pencil Tasks

Organizing Data | **Measurement**



Cyberchase groups > Control ($p < .0001$)

DVD + Web > other groups ($p < .005$ or greater)

DVD + Web and DVD Only > Control ($p < .05$ or greater)

DVD + Web and DVD Only > All Materials ($p < .05$ or greater)

Figure 2: Comparison of the different experimental groups' gains in performance

Nevertheless, although the television series produced stronger pretest-posttest effects than the online games did, online tracking data indicated of the children's online game playing provided a context for children to engage in rich mathematical reasoning – and that this process of reasoning was detectable, not only through in-person observations, but also through data mining of online tracking data. To illustrate we use an example from the game Railroad Repair (see Figure 3 for a screen shot), a game that can be accessed with the following link: http://pbskids.org/cyberchase/games/decimals/ In this game, players fill gaps in a train track by using pieces labeled with decimals between .1 and 1.0. In this game multiple correct solutions are possible. However, each length of track can be used only once per screen, thus requiring children to find multiple ways to make sums and plan ahead to make sure that all of the necessary pieces will be available when needed. Children in our study played the games in pairs, to facilitate conversation that could reveal ideas and strategies as they played. Simultaneously, their gameplay was recorded with a custom built tracking software that recorded their mouse clicks and keyboard input automatically.

Figure 3. Sample screens from *Cyberchase* Railroad Repair game.

We observed many of the children in our study who began by using a *matching strategy* in which they matched the decimals shown (e.g., a .8 piece of track to fill a .8 gap). When this strategy later proved insufficient (e.g., they ran out of .8 pieces or needed to fill a larger gap), some switched to an *additive strategy* (e.g., combining .6 and .2 to fill a .8 gap). When this strategy, too, proved insufficient (e.g., the .2 piece was needed later), some adopted an *advanced* strategy in which they planned ahead, considered alternate ways to make sums, and reserved pieces they would need later.

Comparisons of observation, interview, and online tracking data revealed that these strategies could be detected via data mining too. Tracking data showed consistent patterns of online responses reflecting each strategy (matching, additive, or advanced), and clusters of errors when children's strategies broke down and they shifted to new ones. Consider, for example, some partial output of the tracking software for one player while playing Railroad Repair in Table 1. On the first screen, the tracking software shows evidence of the player adopting a matching strategy, picking up a .4 piece (*piecepress*) and placing it (*piecedrop*) to fill a .4 gap. After accidentally putting the piece in the wrong location (row 2 in the example below), the player then places it correctly (row 4):

Table 1. Sample tracking data from Railroad Repair (first screen).

Row #	Event	Piece	Round	Successful placement?	Elapsed time
1	piecepress	track4	1	n/a	7.161
2	piecedrop	track4	1	wrong	7.272
3	piecepress	track4	1	n/a	8.172
4	piecedrop	track4	1	success	10.2

<u>Table note:</u> Pieces of track are identified by the decimal with which they are labeled in the game (e.g., *track4* indicates a piece labeled .4). Elapsed time is the cumulative number of seconds that have elapsed from the beginning of the game through the event reflected in that row of the table.

For the next several screens, the player continues to use the additive strategy, until arriving at a screen where this strategy is no longer sufficient (see Table 2). After filling several large gaps, the player combines a .5 piece and a .4 piece to fill a .9 gap (rows 13 – 15), only to find that all of the smaller pieces have been used up, which makes it impossible to fill the remaining small gaps on the screen. Recognizing this, the player hits the clear button to clear the screen and start over (row 16). Then, the player starts over by using an advanced strategy, in which the smaller gaps on the screen are filled first (rows 17 – 20), to ensure that the smaller pieces are available when needed. Afterward, the player uses the remaining pieces to fill the larger gaps, which have more flexibility in the variety of ways they can be filled:

Table 2. Sample tracking data from Railroad Repair (fifth screen).

Row #	Event	Piece	Round	Successful placement?	Elapsed time
13	piecedrop	track5	5	success	280.019
14	piecepress	track4	5	n/a	282.065
15	piecedrop	track4	5	success	283.587
16	clear	n/a	5	n/a	285.864
17	piecepress	track6	5	n/a	289.234
18	piecedrop	track6	5	success	290.996

19	piecepress	track5	5	n/a	291.982
20	piecedrop	track5	5	success	293.233

As the above examples illustrate, we found that children‘s shifts in strategies were detectable, not only via in-person observations or interviews, but through online tracking data as well. Changes in strategies were often associated with either clusters of errors (indicating the player trying unsuccessfully to use different pieces to fill a gap), use of the ―clear button (indicating the player‘s recognition that a strategy was not working), and/or simply not having the necessary pieces available to fill gaps that remained on the screen. Thus, we could identify – and differentiate among – instances when children either failed to progress beyond basic strategies, proceeded through more difficult problems via trial and error (without necessarily employing a fundamental change in their thinking), or shifted to more sophisticated strategies over the course of a game.

Altogether our data on children's performance while playing the online games revealed evidence of *transfer* of learning, not only from the treatment to our posttest measures, but also from children's experience with one *Cyberchase* medium to another. This points to a significant strength of learning from multiple media: The lessons learned from one medium can be applied to enrich children's experience while learning from a second medium as well.

Paper-and-pencil measures of attitude revealed only one pair of significant effects: From pretest to posttest, all of the *Cyberchase* groups sustained their interest and (to a lesser degree) confidence in doing school math, while the attitudes of the control group declined. No significant effects appeared for other domains of out-of-school mathematics. However, we also found behavioral evidence of an effect on children's motivation: In two of the three *Cyberchase* online games that were tracked, users of multiple media were more likely to continue playing beyond the end of the game than children in the Web Only group, pointing to their greater motivation to engage in a fun, mathematical activity.

In addition we also observed children engage in self-reliance and autonomous behavior that is atypical of children of this age group and especially while engaged in school tasks. Consider the following excerpt of conversation from two children in our study while playing the Railroad Repair online game we discussed earlier. As they tried to fill gaps in the game‘s railroad track, they had the following exchange:

> *"I think we're supposed to use the 1 and then the 10."*
> *"Uh-oh. Can we subtract?" "This is too confusing." [They clear the pieces from the screen, then start again with a different strategy] "This time, we'll start with the mini-pieces…"*

What is noteworthy here is that when the children had tried something that did not work, and were pretty stuck (above statement: ―this is too confusing), they changed their approach and tried again. They did not seek outside help, and on their own decided to change and try another strategy. Here we can see several of Gee's (2003) learning principles at work. Most notably what he calls the ―psychosocial moratorium principle, that is, that these learners are able to take risks in a space where there are no serious consequences. After all, they can try and try again without being judged about not solving this problem quickly or having made a mistake (and no real world consequence of having a train potentially derail should they fail to fix the problem). Another of Gee's principle that is noteworthy here is what he calls the ―ongoing learning principle, meaning that as the game progresses the learner must undo their routinized strategy to adapt to the new or changed conditions. This moves the learner through cycles of new learning, automatization, undoing automatization, and new reorganized automatization. In the sample conversation, a strategy that had worked well earlier in the game failed and the players had to adapt and tweak a solidly mastered strategy to the new condition. This is not a small fit, as we know too well from seeing students get stuck using a well-learned strategy even when that strategy fails or becomes too inefficient in new problem situations.

Conclusions and Implications

One of the primary questions addressed by this study was how learning from multiple media compares to learning from a single medium, particularly with regard to transfer of learning. The significant effects on problem solving seen in the data suggest that children did engage in transfer of learning, applying the skills and concepts modeled in *Cyberchase* to new problems encountered in the posttest. Indeed, approximately one-third of the children who used *Cyberchase* spontaneously recalled information from *Cyberchase* explicitly while working on one of the posttest tasks, making the source of their inspiration apparent.

Such transfer appeared to occur more among children who used multiple media. In the pretest-posttest problem-solving tasks, many of the observed effects were stronger among the DVD + Web group than among either the DVD Only or (especially) the Web Only group. Contrary to our expectations, the same was not true of the All Materials group, which used all of the same materials as the DVD + Web group plus teacher-led hands-on materials. We cannot be certain why the All Materials group did not perform at the same level as the DVD + Web group, but we hypothesize that it may be because the All Materials group was the only one that used *Cyberchase* materials every day; perhaps this schedule was excessive in light of all of the other constraints on teachers' schedules, and was simply too much for participants to integrate effectively. Further research would be necessary to determine whether an "optimal level" of media use exists. Nevertheless, data from the DVD + Web group suggest that cross-media learning can hold benefits for transfer of learning.

The benefits of multiple media in promoting transfer were even more apparent in our online tracking data. These data revealed that children who used multiple media employed more sophisticated strategies while playing the three online games that were tagged with the tracking software, and produced more correct responses while playing two of the three games. Just as in the posttest tasks, it appears that children took the educational content they encountered in one medium (television and/or hands-on activities) and applied it while engaging with math content in another medium (online games). This transfer of learning supported their interaction with the second medium, allowing children to apply more sophisticated approaches and producing a richer, more successful engagement with the material.

Why, then, did multiple media use contribute toward transfer of learning – and toward greater transfer to posttest tasks? One possible explanation is simply that children who used multiple *Cyberchase* media spent more time engaging with their embedded mathematics content. To some degree, this explanation is probably at least partially correct. Indeed, one of the chief purposes of informal education is precisely that -- to encourage children to spend more time with educational content than they would otherwise. However, spending more time clearly cannot explain the present findings by itself, because the benefits found for the DVD + Web group were not equaled by the All Materials group, which devoted even more time to *Cyberchase* activities. If time were the sole explanation, the gains shown by the All Materials group would have been at least as large as those of the DVD + Web group, if not larger.

A more promising explanation may lie in the concept of *varied practice* discussed earlier (e.g., Gick & Holyoak, 1983; Salomon & Perkins, 1989; Singley & Anderson, 1989). In varied practice, learners are provided with multiple examples of the same concept or repeated practice of a skill in multiple contexts, which increases the likelihood that the learner will apply the material in new tasks or situations as well. As children in the present study encountered mathematics and problem-solving content in multiple *Cyberchase* media, they were clearly engaged in varied practice, especially in those instances where there was close alignment among the content of a related television episode, hands-on activity, and online game. Effects within the online tracking data attest to children's connecting the content of the different media, and even applying the content learned from one medium *while they were learning from the other*. Not only did children gain additional, varied practice by using multiple media, but their engagement with the latter medium was richer and more sophisticated as well. In this way, cross-platform learning has the potential to support learning by contributing to two types of transfer: transfer across educational media platforms (resulting in richer engagement and understanding), and transfer from educational media to new problems or situations encountered subsequently (such as our posttest assessments).

Moreover, it is quite possible that transfer may even be *facilitated* by the presence of the same characters and contexts across media. Past research on transfer of learning has shown that transfer is more likely to occur when two situations appear similar on their face (*surface structure similarity*) than when they are dissimilar on their surface but rest on similar underlying principles (*deep structure similarity*; e.g., Bassok & Holyoak, 1993; Gentner & Forbus, 1991). Thus, for example, encountering *Cyberchase* characters in an online game might lead children to think of other times when they saw the same characters (e.g., on television). This could facilitate the transfer of information and skills from one medium to another, in a way that seeing different characters on television and in a game might not.

Apart from its potential benefits for transfer of learning, the consistency of characters and contexts across media might contribute to attitudinal effects as well. Under Hidi and Renninger's (2006) four-stage model of interest development, interest in a subject such as mathematics originates as interest sparked by the context in which the math is embedded (*triggered situational interest*). Subsequently, interest can be maintained over a longer period by the context (*maintained situational interest*), after which it may evolve into interest in the mathematics itself (*emerging individual interest* and *well-developed individual interest*).

This model fits the present data well. Not only did we find significant associations between naturalistic use of the *Cyberchase* television series and Web site over time, but we also found that children who used multiple media were significantly more motivated to continue playing online *Cyberchase* games. The appeal of *Cyberchase* (as seen in children's appeal ratings at the end of the study) appears to have motivated children's continued use of *Cyberchase*, both over time and across media platforms (as seen in the naturalistic phase).

In Hidi and Renninger's terms, triggered situational interest contributes to maintained situational interest, with the potential to develop into individual interest. Or, in layman's terms, when children become fans of *Cyberchase* and spend more time with various *Cyberchase* media, they are spending more time engaged in substantive, enjoyable informal mathematics activities. Such activities have the potential to contribute to emerging interest in mathematics, as well as to learning.

Our results also have implications for the future design of educational media. When designing future multiple-media projects for informal education, the present data suggest that it is not merely the case that "more" is always better. As noted earlier, children in the DVD + Web group showed more consistent gains than groups that used only one medium – but they also often showed greater gains than children who used all three types of *Cyberchase* media. Further research is needed to determine whether we are correct in hypothesizing that there may be an optimal level of media use in the classroom, beyond which teachers (or even children) find the media less useful – and, if so, what that level might be.

Beyond simply the amount of media used, our data also suggest ways in which media can be designed to maximize their educational power:

Explanation and scaffolding: We believe that one reason why effects were often driven more by the *Cyberchase* TV series than the online games may be that the television series provided more explanation of the relevant mathematical concepts as they used characters and narrative to model successful problem solving. If so, this argues for the need for educational media (in any medium) to provide, not only opportunities for children to exercise their existing and emerging skills, but also explanatory support and scaffolding when needed.

Narrative: Researchers such as Schank and Abelson (1995) have theorized that narrative can serve as a powerful means for conveying information, and for organizing and storing information in memory. The present data are consistent with this view, in that pretest-posttest effects were often strongest among children who viewed the *Cyberchase* television series, and qualitative observations revealed instances of children explicitly referring to *Cyberchase* stories and characters as they worked on problems in the posttest. This is not to say, of course, that non-narrative formats (e.g., games, live demonstrations) cannot also convey educational content effectively. However, our findings speak to the potential for narrative to play an important role in mathematics education.

Complementary media: To facilitate the sorts of transfer of learning and attitudinal effects discussed earlier, consistent characters and contexts, as well as complementary educational content, should be employed across media. In the case of *Cyberchase*, narrative media, such as video, supply explanation of content and models of successful problem solving, whereas participatory (interactive and hands-on) media that provide opportunities for children to exercise these skills themselves. The use of a common world and characters can encourage linkages of content from one medium to another, while the appeal of children's experience in one medium can enhance their motivation to engage with other educational media that employ the same characters.

Convergent media: Together, the above points suggest intriguing possibilities for convergent media, in which the narrative and explanatory power of video, the participatory strength of interactive games, and the potential for scaffolding inherent in adult-mediated hands-on media can be combined in a single media-based experience. For example, consider an interactive game in which the "hint" button pulls up an explanatory video clip, or imagine a video with an embedded interactive game that allows the viewer to use mathematics to help the protagonist achieve her goal in the video.

To conclude, we offer that these four design elements should be considered both by media designers and by educators when designing or using multiple interconnected media with the goals of maximizing their instructional power. As we found in the context of the *Cyberchase* multiple media mathematics project, not only that single media can be effective tools for promoting student learning of mathematics and improving student attitudes about mathematics, but that multiple media can provide a synergistic effect on student learning, although this effect is complex and doesn't just depend on the amount of media use by the students.

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