Children’s Learning from Multiple Media in Informal Mathematics

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EXECUTIVE SUMMARY

Many informal science and mathematics education projects employ multiple media, but studies typically have investigated learning from a single medium, rather than multiple media. The present research, funded by the National Science Foundation, used Cyberchase (a multiple-media, informal mathematics project targeting 8- to 11-year-olds, produced by Thirteen/WNET) to investigate synergy among multiple media components and how they interact to yield cumulative educational outcomes.

A total of 672 children, in nine public elementary schools in Michigan and Indiana, participated in the study. The research incorporated both naturalistic and experimental methods, to investigate children’s use of Cyberchase media, ways in which use of one medium feeds into use of another, and the educational impact of Cyberchase on children’s problem solving and attitudes toward mathematics.

The study was designed to address the following research questions:

1) How does the mathematics learned from multiple media differ from mathematics learned from a single medium?
2) What outcomes derive from engagement with different types of media, and what types of synergy occur?
3) How can reliable research methods be developed to assess contributions of individual media and their interactions?
4) How can informal education projects capitalize on the strengths of each medium?
5) How can media components be designed and employed to best complement each other?

Highlights of the results include the following:

Patterns of Naturalistic Use

- 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.

- Children’s use of Cyberchase also tended to span media; 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 users’ first encounter with Cyberchase occurred long before we began collecting data, the present data cannot determine which medium came first. However,
past research found that children more often begin by watching the TV series and subsequently expand to using the Web site as well.

Learning from Cyberchase

- 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. 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). Interestingly, learning from Cyberchase was not manifest in children’s simply doing a greater number of things while working on the tasks, but rather in their using a greater variety of strategies and heuristics, and in using those strategies and heuristics more effectively. In addition to quantitative, statistical comparisons, qualitative observations revealed that children demonstrated persistence and top-down planning while working on tasks in the posttest. As in past research, effects emerged more consistently in tasks about organizing data (e.g., combinatorics, predicting from data) than in tasks about measurement.

- Surprisingly, however, 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). Although we cannot be certain, we believe that the less consistent performance of the All Materials group may have been influenced by cues from teachers in response to the demands of having to make time for Cyberchase media or hands-on activities every day.

- Effects on problem solving often appeared to be driven more by the TV series than by the online games. 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, 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.

- Although the television series produced stronger pretest-posttest effects than the online games did, online tracking data indicated that the games 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. Parallel to prior research on formal classroom mathematics, children engaged in cycles of increasingly sophisticated mathematical thinking over the course of playing an online game, with shifts in strategies indicated by predictable patterns of responses, such as clusters of errors or use of a “clear” button to try again.
Multiple-Media Learning

- 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.

Attitude

- 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, 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.

Conclusions and Implications

- Together, these data suggest that children use multiple related media during naturalistic use, and that such use can promote both learning and motivation toward engaging in additional, related activities for informal education. Cross-platform learning can elicit transfer of learning, both from one medium to another (resulting in richer engagement with the material) and from educational media to subsequent assessments.

- Indeed, the presence of a consistent world and cast of characters across media has the potential to serve as a bridge that not only elicits, but also facilitates, transfer of learning. In the case of Cyberchase, compelling narrative is used to carry both explanations of content and examples of characters who model successful approaches to problem solving, whereas participatory (interactive and hands-on) media provide opportunities for children to exercise these skills themselves. The use of a common world and characters can encourage children to connect related mathematics content across these media. At the same time, appealing experiences in one medium can stimulate children’s motivation to engage in other educational activities with the same familiar characters. Over time, such experiences have the potential to stimulate interest in the embedded mathematics as well.
INTRODUCTION

Purpose of the Research

Most current informal science and mathematics education projects make use of multiple media to reach their audience. For example, one standard model is comprised of an educational television series accompanied by a Web site and local outreach. Indeed, as media platforms and delivery systems proliferate, this trend shows no signs of slowing down. Not only the production community, but public and private funding agencies, have adopted transmedia – the use of multiple media to tell interconnected stories – as the latest buzzword in creating children’s media (e.g., U.S. Department of Education, 2010). From an educational standpoint, producers and funders assume this combination of media yields benefits for children’s learning and attitudes toward mathematics or science, beyond those that might be provided by one medium alone.

However, almost no research has assessed the synergy among multiple components or explored ways in which their contributions might interact to yield a greater whole. Research on children’s learning from such projects has tended to focus almost entirely on the impact of one predominant component, such as a television series or museum exhibit in isolation. In fact, a sizable research literature indicates that sustained use of educational material within a single medium can -- and does – result in significant improvement in children’s understanding and attitudes (e.g., see reviews by Crane et al., 1994; Falk et al., 2001; Fisch, 2004). Yet, we are unaware of any published studies that attempt to provide comprehensive answers to the question of children’s learning from multiple media, although some more narrowly defined studies have approached aspects of the issues (and some proprietary studies are not available in the research literature).

The present research addresses this gap by investigating what we shall refer to as cross-platform learning – that is, the potential synergy among related media components and how they might interact to yield cumulative educational outcomes.

The study is designed to address the following research questions:

1) How does the mathematics learned from multiple media differ from mathematics learned from a single medium?
2) What outcomes derive from engagement with different types of media, and what types of synergy occur?
3) How can reliable research methods be developed to assess contributions of individual media and their interactions?
4) How can informal education projects capitalize on the strengths of each medium?
5) How can media components be designed and employed to best complement each other?

Theoretical Background

Our approach to 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...
new problem or context. The literature has documented many different types of transfer (Haskell [2001] distinguished among as many as 14 types), 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). Fisch (2004) has applied aspects of these approaches to explain how transfer operates in informal education, such as educational television, as well.

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.

**Cyberchase**

To investigate the nature of cross-platform learning, this study focuses 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.

- **Outreach 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.

In addition to the above components (which serve as the focus of the present research), other materials include activity-based print materials, such as the *Cyberchase Activity Book* for kids and families. A traveling *Cyberchase* museum exhibit (produced in partnership with the Children’s Museum of Houston) provides hands-on mathematics fun for millions of children and families alike.

This wealth of resources makes *Cyberchase* well-suited to the present research, for several reasons:

- *Cyberchase* offers a rich and varied library of existing materials in several media, which provides a powerful resource for both the naturalistic and experimental phases of the research.

- *Cyberchase* materials are designed to be complementary across media. For example, the same mathematics content is often addressed in an episode of the television series, an online game, and a hands-on outreach activity.

- Past research on the *Cyberchase* television series has proven its effectiveness as an educational tool. Sustained viewing has been found to result in statistically significant gains in children’s mathematical problem solving and attitudes toward mathematics (Fisch, 2003; Rockman Et Al., 2002). The documented impact of the television series provides a useful baseline against which to assess outcomes resulting from use of multiple media.

- *Cyberchase* materials are widely viewed and used throughout the United States. As a result, the results of the proposed research pertain directly to real-world practice – they
are more applicable and understandable than they might be if materials were created exclusively for the purposes of the research.

For all of these reasons, we have chosen to use *Cyberchase* materials in the proposed research. However, it is important to remember that, because so little published research literature exists regarding both informal mathematics education and children’s learning from multiple media, the present study not only advances our understanding of the impact of *Cyberchase* itself, but also provides a first step toward understanding children’s STEM learning from multiple media in general.
DESIGN AND METHOD

Sample

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. Essentially the same sample of children participated in both the naturalistic and experimental phases of the research (described below), 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.

At the beginning of the study, we asked children how often they had viewed Cyberchase on television, and how often they had visited its Web site: never (defined as 0 times), a few times (1-5 times), a lot (6-10 times), or a whole lot (more than 10 times). For comparison, we also asked the same questions about two highly popular entertainment programs (SpongeBob Squarepants and Scooby-Doo), another educational series (Liberty’s Kids), and their related Web sites. The following pair of tables summarizes their responses:

<table>
<thead>
<tr>
<th>How often viewed on television</th>
<th>Never (0 times)</th>
<th>A few times (1-5)</th>
<th>A lot (6-10)</th>
<th>A whole lot (more than 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpongeBob</td>
<td>2%</td>
<td>8%</td>
<td>9%</td>
<td>81%</td>
</tr>
<tr>
<td>Scooby-Doo</td>
<td>4%</td>
<td>26%</td>
<td>19%</td>
<td>51%</td>
</tr>
<tr>
<td>Cyberchase</td>
<td>38%</td>
<td>31%</td>
<td>12%</td>
<td>19%</td>
</tr>
<tr>
<td>Liberty’s Kids</td>
<td>89%</td>
<td>7%</td>
<td>1%</td>
<td>3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How often visited Web site</th>
<th>Never (0 times)</th>
<th>A few times (1-5)</th>
<th>A lot (6-10)</th>
<th>A whole lot (more than 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickelodeon (includes SpongeBob Squarepants)</td>
<td>23%</td>
<td>24%</td>
<td>15%</td>
<td>38%</td>
</tr>
<tr>
<td>Cartoon Network (includes Scooby-Doo)</td>
<td>38%</td>
<td>24%</td>
<td>11%</td>
<td>27%</td>
</tr>
<tr>
<td>Cyberchase</td>
<td>75%</td>
<td>15%</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>Liberty’s Kids</td>
<td>98%</td>
<td>2%</td>
<td>0%</td>
<td>1%</td>
</tr>
</tbody>
</table>
As these tables show – and as expected – children’s past viewing of top-rated entertainment programs (*SpongeBob Squarepants* and *Scooby-Doo*) dwarfed their prior exposure to the two educational programs (*Cyberchase* and *Liberty’s Kids*). The vast majority of children had watched both entertainment programs more than a few times (90% for *SpongeBob Squarepants* and 70% for *Scooby-Doo*) – more than twice as many as had seen *Cyberchase* more than a few times.

In all four cases, children reported that they had watched each television series more often than they had visited its related Web site. This is consistent with prior research on *Cyberchase* media use (e.g., Fisch, 2005), as well as more general research on children’s media use, which has found children to spend far more time watching television than going online (e.g., Rideout, Foehr, & Roberts, 2010).

Given the children’s limited experience with *Cyberchase*, we expected that their prior exposure would not pose a confound for the present research. In fact, statistical analysis subsequently confirmed that there was no confound, as will be discussed in the Results section.

### Research Design

One key consideration in designing any research study is whether to adopt a naturalistic approach, which allows findings to be generalized easily to the real world, or an experimental approach that provides a greater degree of control and allows researchers to attribute causality among the variables measured. To gain the advantages of both approaches, the present research was comprised of two phases. 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.

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>April-June</td>
<td>Background measures</td>
</tr>
<tr>
<td>(start and end dates</td>
<td>Assessment: Naturalistic phase pretest</td>
</tr>
<tr>
<td>staggered to fit school</td>
<td>Naturalistic phase, part 1: approximately 6 weeks</td>
</tr>
<tr>
<td>schedules)</td>
<td></td>
</tr>
<tr>
<td>October-December</td>
<td>Naturalistic phase, part 2: approximately 6 weeks</td>
</tr>
<tr>
<td>(start and end dates</td>
<td>Assessment: Naturalistic phase posttest/</td>
</tr>
<tr>
<td>staggered to fit school</td>
<td>Experimental phase pretest</td>
</tr>
<tr>
<td>schedules)</td>
<td></td>
</tr>
<tr>
<td>January-March</td>
<td>Experimental phase: 8-week treatment period</td>
</tr>
<tr>
<td>(start and end dates</td>
<td>Assessment: Experimental phase posttest</td>
</tr>
<tr>
<td>staggered to fit school</td>
<td><em>Cyberchase</em> interviews with teachers and children</td>
</tr>
<tr>
<td>schedules)</td>
<td></td>
</tr>
</tbody>
</table>
At first glance, one might wonder whether use of Cyberchase during the naturalistic phase would pose a confound for the experimental phase. This is not the case, because the very nature of the naturalistic phase meant that children used (or did not use) Cyberchase media just as they would have in the absence of any research. Indeed, because we had a detailed record of use before the experimental treatment, we were able to run statistical analyses of experimental data that controlled for prior use – a level of control that would not have been possible if the children had not participated in the naturalistic phase.

**Naturalistic Phase**

As noted above, the primary goal of the naturalistic phase was to monitor naturalistic use of the Cyberchase television series and Web site over time. On one level, this was necessary simply to determine whether children actually do engage with an informal education project such as Cyberchase across several media platforms, or whether some children choose to watch the television series while others use the Web site (in which case the question of synergy across media platforms would be interesting but have little real-world relevance). On a second level, assuming that children make use of multiple media, naturalistic data were needed to explore how use of one medium for informal mathematics education might feed into use of other media (with implications regarding both synergy among media effects and children’s motivation to engage in informal educational activities). Third, naturalistic data could help us identify predictors of children’s use of Cyberchase, such as demographic factors (e.g., does use of Cyberchase differ as a function of children’s pre-existing math ability?) and how use of Cyberchase fits into their overall pattern of media use. Finally, although the nature of the experimental phase was better suited to investigating children’s learning from Cyberchase, we were also interested in whether naturalistic use was associated with differences in children’s problem solving performance or attitudes toward mathematics. (Note, however, that we did not find enough naturalistic use to address the latter issue, but significant effects did emerge as a result of more extensive exposure during the experimental phase.)

The naturalistic phase tracked children’s use of Cyberchase media over a 12-week period, approximately six weeks in the spring (when participants were in third grade) and six weeks in the fall (when they were in fourth grade). During this time, children were free to use (or not use) any Cyberchase media at home as usual. Once each week, they were asked to record any use of Cyberchase materials in a weekly “Cyberchase journal.”

**Measures.** 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.

Samples of these measures can be found in Appendix A.

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:

- To establish causality in studying the impact of multiple media on children’s mathematical problem solving and attitudes toward mathematics.

- To assess how effects might differ as a function of children’s exposure to different combinations of media components.

- 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 groups¹:

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¹ The constraints of daily classroom schedules required us to assign intact classrooms, rather than individual children, to each experimental group. However, to ensure that no systematic differences between classrooms would be confounded with the experimental treatment, multiple classrooms were assigned to each treatment group, and all of the treatment groups were roughly equivalent in their representation across age, gender, ethnicity, and mathematics ability. Indeed, subsequent statistical analysis confirmed that there was no significant
• **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*).

Exposure to the various *Cyberchase* media was designed to emulate real-world use of these materials. Past surveys (Fisch, 2005, 2006) and Nielsen ratings data indicate that, of the *Cyberchase* media components that currently exist, the television series has the greatest reach, followed by the Web site. (The greater use of television over Web was also evident in data from the naturalistic phase of the present study, as reported in the Results section below.) Thus, most of the treatment groups were exposed to the television series and/or Web site. Similarly, each group’s frequency of exposure was informed by data on frequency of real-world use, as well as the maximum that schools and after-school programs were able to accommodate.

It is worth noting that, in designing the treatment, we recognized that children would spend more time with some forms of *Cyberchase* media (e.g., television) than others (Web site or hands-on activities), which could contribute toward some media producing greater effects than others. However, the alternative would have been to have children spend equal time with each media component, which is not representative of naturalistic use; the artificiality of such a treatment would have limited the generalizability of our results to the real world. For this reason, and because the purpose of the research was to investigate synergy among media rather than to attempt to determine which medium is “best” as a tool for informal education, we decided to align the treatment with real-world use so as to maximize the generalizability of the data.

To select specific television episodes, online games, and hands-on games for the treatment, we reviewed the available *Cyberchase* library, and chose materials that fell within two broad areas of mathematics content: organizing data (e.g., graphs, combinatorics, predicting from data) and measurement (e.g., size and scale, elapsed time, proportional reasoning). In some weeks of the
treatment, mathematics content was closely aligned across media; for example, one television episode, one online game, and one hands-on activity all concerned “body math” – that is, proportional relationships among body parts (e.g., a person’s foot is approximately the same length as his/her forearm). In other weeks, the mathematical topic was not closely aligned across media, although the same sorts of problem-solving strategies and heuristics could be applied in all three. A complete list of all of the materials in the treatment, along with the schedule under which they were administered, is presented in Appendix B.

Children in the No Exposure group were not presented with any of the Cyberchase materials. Instead, they watched three episodes per week of the television series Liberty’s Kids. Like Cyberchase, Liberty’s Kids is an animated, educational series that is aimed at approximately the same age group. However, whereas the educational content of Cyberchase focuses on mathematics, Liberty’s Kids deals with American History at the time of the Revolutionary War.

**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).

Each of these measures is described in greater detail below.

**Measures – problem solving.** Several past studies of children’s mathematics learning from television have employed hands-on problem-solving tasks in the context of task-based interviews (e.g., Fisch, 2003; Hall, Esty, & Fisch, 1990). The present study, too, included hands-on tasks, but the design of our problem-solving assessments was informed largely by the thought-revealing or model-eliciting activities approach described in the mathematics education literature (e.g., Lesh & Doerr, 2002; Lesh, Hamilton & Kaput, 2007; Lesh et al., 2000). In essence, thought-revealing activities are a means of blending instruction and assessment, by presenting students with rich, meaningful problems that can be approached in a variety of ways (including both mathematical and non-mathematical approaches). Students work on each problem in groups, with the goal of not only solving the problem, but also describing a more generalized procedure by which other, similar problems can also be solved. Each problem is designed to yield insight into the students’ mental models of its mathematics content, and how these models evolve; typically, students’ mental models become more sophisticated and accurate as the group continues to work on the problem over an extended period of time (sometimes several days).
To serve as a useful tool for a pretest-posttest study, as opposed to classroom instruction, the thought-revealing activities approach had to be adapted in several ways. First, and perhaps most important, thought-revealing activities for the classroom are designed to serve as an instructional tool as well as an assessment. Yet, for the purposes of a research study, the educational value of the assessment tasks could not be so strong as to overwhelm any effects of the experimental treatment (although they still needed to be rich enough to lend insight into the process of children’s problem solving). To that end, we limited both the scope of each task and the amount of time that children were given to work on it. Second, because of these imposed limits, we were unsure whether children would be able to not only solve the problem but also reflect on and abstract their solution into a more generalized procedure for solving other problems in the future. Thus, apart from asking children for their solutions, we also asked them two levels of questions for each problem: First, we asked them to recount the process they used to solve this particular problem, and then we asked them to describe a process that could be used to solve similar problems in the future. Third, for the purposes of an experimental study, we had to create coding schemes that operationalized aspects of children’s process and solutions in standardized ways that would be reliable from pretest to posttest and across experimental groups. Finally, in addition to hands-on tasks, we also devised paper-and-pencil problem-solving tasks (and related coding schemes) that captured the same spirit as the hands-on tasks, but could be completed on paper by children working alone.

Children completed paper-and-pencil assessments of problem solving at three points: at the beginning of the naturalistic phase, at the end of the naturalistic phase, and at the end of the experimental phase. Thus, the naturalistic and experimental phases were each framed by a pretest and posttest, with the second wave of assessment serving simultaneously as both the posttest for the naturalistic phase and the pretest for the experimental phase.

During each wave of assessment, children were given two paper-and-pencil tasks, one of which was a measurement task, and the other involved organizing data. Each measurement task presented children with a figure that included four zigzagging paths; children were asked to figure out which of the presented paths was longest or shortest. Children were awarded points based on their use of measurement and whether they indeed chose the longest/shortest path. Each organizing data task presented children with a table of data (e.g., the amount of food collected in response to various methods of publicizing a food drive for needy families), and asked them to interpret the data in the table and make predictions about what might happen in the future given current trends. Children were awarded points based on their ability to interpret the table, and to use data to make and justify well-founded predictions. Pretest and posttest tasks were essentially isomorphic to each other, employing the same underlying mathematics in a different surface context. Samples of the paper-and-pencil tasks, and their coding schemes, can be found in Appendix C.

Hands-on tasks were administered at the beginning (pretest) and end (posttest) of the experimental phase. As in the paper-and-pencil assessments, children completed two hands-on tasks each time, a “body math” task that required measurement and proportional reasoning, and an organizing data task that involved combinatorics. Whereas the paper-and-pencil tasks were completed by each child individually, however, children worked on the hands-on tasks in groups...
of three. Researchers observed each group of children as they worked on the task, and interviewed them afterward about their process and solution.

For example, the pretest body math task cast children in the role of detectives who had to figure out as much as possible about the perpetrator of a mysterious crime.

[A corner of the room is set up as follows, to simulate a crime scene (note: the measurements are for reference; they are not be told to children, although children can choose to measure the objects themselves):

- A 5-foot-wide frame sits on the floor in front of the wall. Torn paper hangs around the inside edge of the frame, to simulate a picture that’s been cut out. There are matching dirty handprints on the left and right edges of the frame where someone held it.
- A pair of 10-inch-long footprints face the wall.
- A hat (20” around) lies nearby, with one brown hair (represented by yarn) inside]

In this puzzle, we’re going to pretend that you are detectives. Famous detectives like Sherlock Holmes can tell a lot about crooks from the clues they leave behind. For example, they can use footprints to figure out how tall someone is, how much they weigh, whether they walk with a limp, and so on. Fingerprints can tell them even more, because everybody’s fingerprints are different. But in this crime, the crook didn’t leave any fingerprints behind, although there are some other kinds of clues you can use. Ready?

Here’s what happened: Imagine this is a museum where a priceless painting was stolen. [While demonstrating:] The thief came in at night, stood here [in footprints], and took the painting off the wall [one hand on either side of frame], leaving these dirty handprints on the frame. Then, the thief cut out the painting, rolled it up, and ran away. But during the getaway, the thief’s hat fell off. It’s lying right here, with a blonde hair inside.

Your job is to use these clues to figure out as much as you can about what the thief looks like: how tall the thief is, what color hair the thief has, and so on. You might be able to tell a lot about the thief, or maybe just a little. Either way, each thing you figure out will help narrow down the search, and that’ll make it easier to catch the crook. So each piece of information is important.

To help you, you can use anything you want from this kit of detective tools – or you don’t have to use any of the tools at all. [See Appendix F for list of materials in kit.]

Okay, now I’m going to give you a little time to figure out the puzzle. You can do whatever you want to help you figure it out, and if you want to use any of this stuff [kit], you can. I’ll be over there working if you need me. Otherwise, when you’re ready, you can call me and we’ll talk about what you think the thief looks like. Any questions? Okay, let’s begin.

(continued on next page)
This mystery could be approached in a variety of ways, both mathematical and non-mathematical (e.g., using the brown “hair” as evidence that the thief had brown hair). A mathematically complete and sophisticated answer, however, required children to apply proportional reasoning to use presented clues (e.g., the size of the footprints and/or distance between handprints) and thus draw inferences about the thief’s height and the size of various parts of his or her body. Similarly, the posttest task cast children as sculptors in a wax museum whose task was to figure out dimensions for a life-size statue of basketball player Shaquille O’Neal, based on a photo and an outline of his footprint.

Organizing data tasks required children to construct a schedule for a series of ping pong or soccer matches, providing for all possible combinations of competitors while also meeting several constraints for scheduling. As in the body math tasks, this pair of tasks could be approached in a variety of ways, such as using multiplication for combinatorics, or physically manipulating cards with competitors’ names to create possible matches.

Children’s performance in each hands-on task was coded in two ways, one reflecting the process they used while working on the task, and the other representing the mathematical sophistication of the group’s solution. For process, a detailed coding scheme was devised to identify the strategies and heuristics that children used while working on the task (e.g., standard or nonstandard measurement, looking for patterns, trial and error). This scheme focused on the following strategies and heuristics.

(Detective task continued)

PART 2

Good news: Thanks to your description, the police caught the thief and got the painting back! The Chief of Police is so happy that she wants you to teach all the other detectives how to catch crooks just like you did.

So now, I want you to think about how you’d teach someone else to use these kinds of clues to figure out what a crook looks like. Remember, the Police Chief doesn’t want you to come up with a description of one crook this time. Instead, the Chief wants you to give the detectives some directions for how to figure it out, so they can use the same steps every time they have to solve this kind of crime.

Take a little time to think about it. When you’re ready, let me know and we’ll talk about what you’re thinking. Any questions? Okay, let’s begin.
The coding scheme for solution scores identified several levels of sophistication, based on the key mathematical concepts underlying the task and the systematicity of the solution. Because children worked on the task in groups of three, one process score and one solution score was assigned to each triad as a whole.

Coding for the paper-and-pencil tasks was similar, with two primary differences. Because researchers did not observe children as they worked on the paper-and-pencil tasks, children were assigned solution scores but not process scores. Also, because children completed these tasks individually, every child received a score for each paper-and-pencil task (whereas scores for hands-on tasks were assigned to groups rather than individual children).

Samples of the hands-on tasks, along with the coding schemes for each task’s solution score, can be found in Appendix D. The coding scheme for process scores can be found in Appendix E. Note that the same coding scheme was used to assign process scores for all of the hands-on tasks.

Measures – online tracking data. In keeping with current trends in mathematics education toward blending instruction and assessment (e.g., Kelly & Lesh, 2000; NCTM, 1993), several Cyberchase online games served simultaneously as both instruction (i.e. part of the experimental treatment) and assessment (i.e. a means of gauging children’s mathematical problem solving). Three games were chosen to serve in this capacity: Railroad Repair, a game about adding decimals to create given sums (http://pbskids.org/cyberchase/games/decimals/); Sleuths on the 

<table>
<thead>
<tr>
<th>Heuristics Coded in Process Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Recall information</td>
</tr>
<tr>
<td>• Gather information</td>
</tr>
<tr>
<td>• Measure: Ruler</td>
</tr>
<tr>
<td>• Measure: Nonstandard manipulatives</td>
</tr>
<tr>
<td>• Estimate, approximate</td>
</tr>
<tr>
<td>• Calculate</td>
</tr>
<tr>
<td>• Manipulate: Use objects</td>
</tr>
<tr>
<td>• Manipulate: Change objects</td>
</tr>
<tr>
<td>• Trial &amp; error, guess &amp; check</td>
</tr>
<tr>
<td>• Write: List, table, chart</td>
</tr>
<tr>
<td>• Write: Picture, diagram</td>
</tr>
<tr>
<td>• Write: Other</td>
</tr>
<tr>
<td>• Transform problem</td>
</tr>
<tr>
<td>• Look for patterns</td>
</tr>
<tr>
<td>• Reapproach problem</td>
</tr>
<tr>
<td>• Reasonableness</td>
</tr>
<tr>
<td>• Alternate ways to solve</td>
</tr>
<tr>
<td>• Related problems</td>
</tr>
</tbody>
</table>
Loose, a “body math” game about proportional reasoning (http://pbskids.org/cyberchase/games/bodymath/); and Pour to Score, a game about measuring and creating given quantities of liquid (http://pbskids.org/cyberchase/games/hardproblems/). Custom-built tracking software was created to record each player’s mouse clicks and keyboard input automatically as he or she played the game. Parallel to the hands-on assessments discussed above, detailed coding schemes were created to draw on characteristic patterns of responses and errors to identify the sophistication of the player’s strategies for playing the game, as well as the number of items he or she answered correctly.

For further detail on this innovative methodology, and its potential for assessing mathematical problem solving, please see Fisch et al. (in press). Sample coding schemes can be found in Appendix G of the present report.

**Measures – attitude.** In approaching attitudes toward mathematics, we faced a significant challenge, because existing measures of mathematics attitude (e.g., Fennema & Sherman, 1976) are of limited usefulness in the context of informal education, for several reasons. First, their items typically focus heavily on in-school mathematics, whereas the focus of informal education is outside of school. Second, they typically make extensive use of the word “math,” which children (and adults) often interpret as meaning little more than numbers and arithmetic, rather than the far broader range of subjects that actually comprise mathematics (e.g., Debold et al., 1990; Kulm, 1980).

For these reasons, we created new measures to assess attitude both in and outside the context of school. Our assessments were informed by Hannula’s (2002) recent approach to assessing attitude in multiple contexts, as well as the research literature on interest and motivation (e.g., Dweck & Elliott, 1983; Hidi & Renninger, 2006; Hoffman, Krapp, & Renninger, 1998) and measures used in past summative studies of the impact of informal mathematics and science education (e.g., Fay et al., 1995; Debold et al., 1990; Nicholson, Hamm, & Weiss, 1991). These measures focused on three dimensions of attitude toward mathematics: interest, confidence, and motivation.

One paper-and-pencil measure (administered in the experimental pretest and posttest) was a set of interest and confidence scales, based on the scale used in Fay et al.’s (1995) summative evaluation of the science and technology television series, *Cyberchase*. To avoid ambiguous uses of the word “math,” the scale instead asked children to rate their interest and confidence in a variety of specific activities. Four categories of activities were included:

- **Cyberchase items**: Activities that corresponded directly to mathematics-based activities from the *Cyberchase* materials included in the treatment
- **Non-Cyberchase items**: Mathematics-based activities that were not included in the *Cyberchase* materials in the treatment (although they are the subjects of other *Cyberchase* materials that were not used in the study)
- **School math items**: Activities typical of mathematics in school
- **Non-math items**: Activities that were less inherently mathematics-based
For example, some items in this measure asked children to rate their interest and confidence in figuring out: ways to keep track of time without using a clock (Cyberchase item), whether a game of chance is fair for all of the players, (non-Cyberchase item), the best way to study for a math test (school math item), and the history of their home town (non-math item). Interest in each activity was rated on a five-point scale of very interesting, a little interesting, so-so, a little boring, or very boring. Confidence in one’s ability to do the activity was rated on a five-point scale of definitely could do it, maybe could do it, not sure, maybe could not do it, and definitely could not do it.

A second paper-and-pencil measure (administered only in the experimental posttest) grew out of past literature that has examined motivation in terms of children’s goals and orientations toward challenge – specifically, whether their motivation is intrinsic to the task itself (often referred to as learning goals or mastery goals) or stems from extrinsic factors such as external praise or rewards (often referred to as performance goals; see, e.g., Pintrich & Schunk, 2002). In this measure, children were presented with three stories. Each story concerned three children who encounter some difficulty while working on a difficult problem; one of the children suggests that they continue to work because the task is interesting (consistent with learning/mastery goals), a second suggests continuing simply because they started the task and so should finish it (consistent with performance goals), and a third suggests asking someone else to tell them the right answer (performance goals). In keeping with Hannula’s (2002) recommendation of considering context while measuring attitudes toward mathematics, the problem in each story was set in different context: solving a classroom math problem, attempting to complete a level in a video game, and making a gift for a parent. Children were asked to indicate the characters in each story who sounded most and least like themselves, and to explain why. Samples of these paper-and-pencil measures can be found in Appendix H.

Finally, apart from its role as a problem-solving assessment, we also drew on the online tracking data discussed above to provide a behavioral measure of motivation. Typically, it is difficult to use variables such as time spent in a mathematical task as a measure of motivation, because skill and motivation are confounded; if a child spends only a brief period of time in the task, is it because he or she is unmotivated, or highly skilled and able to complete the task quickly? In our online tracking data, however, pilot data revealed that some players not only completed an entire game, but also continued to play again, beyond the end of the game. By restricting our motivation analysis to only those children who reached the end of the game, we were able to control for ability (because all of these children had sufficient ability to reach the end of the game); continuing to play beyond the end of the game was a clear indicator of greater motivation than simply stopping when the player reached the end. Thus, by comparing children in the Web Only group to children who used multiple Cyberchase media, we could determine whether the use of multiple media increased children’s motivation to engage further in mathematics-based games.

Reliability and validity. Although all of our measures were grounded in past literature on research and math assessment, all of them were created for the purposes of this research. Thus, prior to the study, we conducted an extensive pilot phase to test the reliability and validity of the measures, discard any measures that did not perform adequately, and refine the design of the measures that remained. During this time, the research design and measures were also reviewed.
and approved by the institutional review board at Michigan State University, to ensure compliance with standards for the ethical treatment of human subjects.

As reported elsewhere in greater detail (Fisch, 2007), the measures were found to be sufficiently valid and reliable. Interrater reliability exceeded $r = .90$ ($p < .01$) for paper-and-pencil problem-solving tasks and $r = .80$ ($p < .01$) for solution scores to hands-on tasks, and there was 79% agreement regarding the problem-solving heuristics used in hands-on tasks (Cronbach’s alpha = .69). Performance on both types of tasks was significantly correlated with both teacher ratings of math ability and performance on a scale comprised of items taken from the mathematics portion of the fourth-grade National Assessment of Educational Progress (NAEP), although a few of these correlations narrowly missed attaining significance due to the small sample size used in the pilot test.

Principal component analyses suggested that the subscales of the attitude scales were well defined, in that virtually all of the mathematics-based items (Cyberchase, non-Cyberchase, and school math) clustered around one factor, whereas the non-math item *Figuring out how to take care of a pet* did not. Interrater reliability for the attitude scales was quite high: $r = 1.00$ ($p < .01$) for the interest scale, and $r = .996$ ($p < .01$) for the confidence scale.

*Supplementary interviews.* To aid in interpreting the data from the above measures, the posttest was followed by supplementary interviews conducted individually with participating children and teachers. Child interviews focused on children’s experience with *Cyberchase* during the treatment, any follow-up activities or discussion that might have occurred at home, and children’s perceptions of *Cyberchase*’s appeal and embedded problem solving, as well as their perceptions of their own learning (if any). Because this interview concerned *Cyberchase* itself, it could only be administered to those experimental groups that used *Cyberchase* materials (i.e. not the No Exposure group).

Teacher interviews gathered information on topics such as the teachers’ perceptions of their students’ learning from *Cyberchase*, how *Cyberchase* was integrated into their classrooms, and their perceptions of *Cyberchase*’s educational value and usefulness in the classroom.

Interview protocols for the child and teacher interviews are presented in Appendix I.
RESULTS

Patterns of Use of Multiple Media (Naturalistic Phase)

Overview of Results: Naturalistic Use

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, and a similar pattern was found for month-to-month use of the Web site.

Children’s use of Cyberchase also tended to span media; each month, children who watched the TV series more frequently also tended to visit the 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 users’ first encounter with Cyberchase occurred long before we began collecting data, the present data cannot determine which medium came first. However, past research found that children more often begin by watching the TV series and subsequently expand to using the Web site as well.

Overall Amount of Use

Earlier in this report, we reported the degree to which children said they had watched the television series or visited the Web site prior to participating in the study (see the description of the sample on page 10). Children’s use of Cyberchase media during the naturalistic phase was fairly consistent with their earlier self-reports of prior use. The following two tables draw on data from children’s weekly Cyberchase journals, in which they recorded the number of times they watched Cyberchase or SpongeBob Squarepants on television, or visited the related Web sites during the naturalistic phase. For the sake of comparison, we have recoded the data into the same categories used on page 10.

<table>
<thead>
<tr>
<th>Number of children who watched on TV during the naturalistic phase</th>
<th>0 times</th>
<th>1-5 times</th>
<th>6-10 times</th>
<th>More than 10 times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyberchase</td>
<td>30%</td>
<td>42%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>SpongeBob</td>
<td>10%</td>
<td>10%</td>
<td>11%</td>
<td>69%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of children who visited Web site during the naturalistic phase</th>
<th>0 times</th>
<th>1-5 times</th>
<th>6-10 times</th>
<th>More than 10 times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyberchase</td>
<td>35%</td>
<td>47%</td>
<td>11%</td>
<td>7%</td>
</tr>
<tr>
<td>SpongeBob</td>
<td>54%</td>
<td>21%</td>
<td>9%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Several points regarding these data are noteworthy:
Children’s overall amount of use of Cyberchase media during the naturalistic phase was fairly consistent with their earlier self-reports of use prior to the study. This consistency lends validity to the data from both measures, and suggests that their level of Cyberchase media use during the naturalistic phase was indeed naturalistic; it does not appear to have been overly inflated by the children’s knowledge that they were participating in a research study.

During the naturalistic phase (as in their use prior to the study), children watched SpongeBob Squarepants more often than Cyberchase during the naturalistic phase. Again, this is consistent with Nielsen ratings that show SpongeBob Squarepants to be highly popular among this age group. Interestingly, use of the SpongeBob Web site was somewhat split; although more children visited the SpongeBob site frequently (more than 10 times) than Cyberchase, more children never visited it as well.

As mentioned earlier, the lower levels of use for Cyberchase held both advantages and disadvantages for the present study. On the one hand, there was not enough use to produce significant pretest-posttest effects on problem solving during the naturalistic phase (although such effects did arise as a result of more extensive use during the experimental phase). On the other hand, because children did not spend enough time with Cyberchase to produce educational effects during the naturalistic phase, the results of the experimental phase could be interpreted cleanly; there was no confounding effect stemming from children’s earlier use during the naturalistic phase.

Still, although naturalistic use may not have been sufficiently prevalent to elicit change in problem-solving performance, it was sufficient to explore patterns of multiple-media use over time. Path analysis, via structural equation modeling, was conducted to address issues such as whether children’s use of each Cyberchase medium was consistent over time, whether use of one form of Cyberchase media was associated with use of another, and whether use might be predicted by demographic variables or children’s more general use of television or the Web. We consider each of these issues in turn.

**Consistency of Use Over Time**

The following figures represent relationships among children’s use of a given medium (e.g., watching the Cyberchase television series) from month to month during the naturalistic phase. All of the arrows and numbers shown are statistically significant at $p < .05$ or greater; missing arrows reflect relationships that were not statistically significant.

Please note that the numbers shown in these figures are estimates of the strength of each path, not correlation coefficients (and, thus, should not be interpreted as correlations). However, like correlations, these values indicate the strength of each relationship, and the degree to which one variable predicts another.

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2 Further detail on these and other statistical analyses presented in this report can be found in Appendix J.
Cyberchase TV

April → May → Oct → Nov → Dec

-0.54 → -0.12 → -0.11 → |0.84| → -0.11

Cyberchase Web

April → May → N.S. → Oct → Nov → Dec

-0.59 → 0.13 → 0.09 → |0.42| → 0.08

(May N.S. to Nov and Dec)

SpongeBob TV

April → May → Oct → Nov → Dec

-0.81 → 0.36 → |0.92| → 0.94 → 0.26

SpongeBob Web

April → May → Oct → Nov → Dec

-0.55 → 0.31 → |0.78| → 0.82 → 0.11
As these figures illustrate, use of each form of Cyberchase media (TV and Web site) was fairly consistent over time. Those children who chose to watch Cyberchase on TV in one month also tended to do so in subsequent months. A similar pattern was found for month-to-month use of the Web site, and use of SpongeBob Squarepants was found to be consistent over time as well. Thus, use of each Cyberchase medium typically was not a one-time experience. Rather, it tended to continue at a similar level over an extended period of time (regardless of whether a particular child chose to use Cyberchase many times each month or only a few times per month). As one might expect, relationships between months were generally strongest for neighboring months; for example, the path estimate between Cyberchase television viewing in May and December was .18, but the path estimate between November and December was .95 (although both estimates were statistically significant).

The one notable outlier to this trend was children’s viewing of the Cyberchase television series in April. Unlike the other months (and other media), Cyberchase viewing in April was negatively related to the remaining months. Three possible explanations of this unexpected result seem likely: (a) It is possible that viewership of Cyberchase was inflated in April due to children’s curiosity upon entering the study (whereas most children were already familiar with SpongeBob Squarepants, so no such effect appeared for the latter series). (b) Viewership in April may have been inflated due to Spring break, during which children had more free time available to watch Cyberchase. (c) Although children in all of the participating schools completed Cyberchase journals for 12 weeks during the naturalistic phase, the constraints of differing school schedules caused some schools to begin the journals sooner than others. Because only some of the children began filling out their journals in April, the restricted range of data may have affected the analysis for April (whereas May, by contrast, was positively related to all of the remaining months). We suspect that all three of these factors may have contributed to some degree.

Despite this one unexpected finding for television in April, however, the bulk of the data make it clear that the degree to which children use a given medium for informal education (like their use of a given medium for entertainment) tends to remain stable over a period of several months.

**Cross-Platform Use: Television and Web**

Just as use of a given medium was found to be relatively stable from month to month, children’s use of Cyberchase also tended to carry over from one medium to another. The following pair of figures illustrates relationships between use of a given television series and related Web site within each month. As above, all of the arrows and path estimates shown in the figures are statistically significant at $p < .05$ or greater.
As the above figures demonstrate, use of the *Cyberchase* television series and Web site were significantly related in every month. The same was true, in almost every month, for *SpongeBob Squarepants* as well. Thus, these data are consistent with one of the central assumptions underlying the present research: At least in the context of *Cyberchase*, children will engage with informal educational media across platforms when related multiple media are available.

With that in mind, a natural next question might be which medium “comes first” – whether use of television typically leads to use of a related Web site or vice versa. To explore this question, we conducted a set of path analyses that compared use of one medium in a given month to use of the other medium in the following month. The results of these analyses are summarized in the following pair of figures.
TV-Web relationship between months

<table>
<thead>
<tr>
<th>SpongeBob TV</th>
<th>April</th>
<th>May</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpongeBob Web</td>
<td>April</td>
<td>May</td>
<td>Oct</td>
<td>Nov</td>
<td>Dec</td>
</tr>
</tbody>
</table>

No significant relations found between months

As the above figures illustrate, the relationship between television and Web did not always proceed in the same direction. For *Cyberchase*, there were two instances in which the relationship proceeded from television to Web, and one in which it proceeded in the opposite direction. (In addition, as in the analysis of television viewing across months, television viewing in April was an outlier, in that it was negatively related to Web use in May.) For *SpongeBob Squarepants*, surprisingly, there were no instances in which use of one medium predicted use of the other medium in the following month, despite the fact that significant relationships between television and Web did emerge within months, as discussed earlier.

We believe that clearer directional trends were not found because the children who used either *Cyberchase* or *SpongeBob* during the naturalistic phase typically were not using it for the first time (as seen in our data on children’s media use prior to the study). Because they already had some experience with one or both media platforms, the data from the naturalistic phase could not truly speak to the question of which platform “came first.”

However, prior research does suggest an answer to this question in the case of *Cyberchase*. Nielsen ratings and online metrics indicate that both *Cyberchase* and *SpongeBob Squarepants* reach larger audiences on television than online (and American children spend considerably more time with television than the Web overall; Rideout et al, 2010), and a survey of parents of *Cyberchase* viewers found that children typically began watching *Cyberchase* on television at younger ages than they began using the Web site (Fisch, 2005). Certainly, the path between television and Web use can proceed in both directions -- and, indeed, the potential for multiple entry points is one of the strengths of multiple media. In most cases, though, it appears that children first encounter projects such as *Cyberchase* on television, and those children who find the material sufficiently appealing to become *Cyberchase* fans continue to engage with *Cyberchase* over time and across other media platforms.

**Predictors of Use**

Having established that use of *Cyberchase* media was consistent over time and spanned multiple media platforms, we next turn to the question of how use of these media might be predicted or influenced by use of other media and external demographic variables. To do so, we considered several indicators of children’s use of *Cyberchase* media: their reports of *Cyberchase* television and Web use prior to the study, and their use during the naturalistic phase (as reflected in the number of times they used each medium and the amount of time spent). The following
The correlation matrix summarizes the degree to which each of these variables was predicted by children’s gender, ethnicity (coded as minority vs. nonminority), mathematics ability, and whether they cited math as their favorite subject in school, as well as their use of Cyberchase media prior to the study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cyberchase TV viewing (before study)</th>
<th>Cyberchase Web use (before study)</th>
<th>Number of times watched Cyberchase on TV (naturalistic phase)</th>
<th>Number of times visited Cyberchase Web site (naturalistic phase)</th>
<th>Total time spent: Cyberchase TV (naturalistic phase)</th>
<th>Total time spent: Cyberchase Web site (naturalistic phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.04</td>
<td>0.09*</td>
<td>0.02</td>
<td>0.06</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>-0.11</td>
<td>0.11</td>
<td>0.07</td>
<td>0.11</td>
<td>0.07</td>
<td>0.13*</td>
</tr>
<tr>
<td>Math ability</td>
<td>-0.03</td>
<td>0.02</td>
<td>-0.08</td>
<td>0.01</td>
<td>-0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Favorite subject math</td>
<td>-0.05</td>
<td>-0.03</td>
<td>0.07</td>
<td>0.11</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>Cyberchase TV viewing (before study)</td>
<td>---</td>
<td>0.49***</td>
<td>0.27***</td>
<td>0.10</td>
<td>0.26***</td>
<td>0.09*</td>
</tr>
<tr>
<td>Cyberchase Web use (before study)</td>
<td>0.49***</td>
<td>---</td>
<td>0.26**</td>
<td>0.25***</td>
<td>0.25***</td>
<td>0.32***</td>
</tr>
</tbody>
</table>

*Statistically significant, p < .05.  ***Statistically significant, p < .001.

Data from Nielsen ratings and past studies have indicated that Cyberchase is successful in reaching both boys and girls and children of various ethnicities (e.g., Fisch, 2003, 2005). As this table shows, the present data confirm these findings. Neither gender nor ethnicity predicted the degree to which children chose to watch Cyberchase on television, suggesting once again that the series had roughly equivalent reach among a diverse audience. Only two correlations regarding the Web site reached significance, in that girls were more likely to have visited the site prior to the study ($r = .09, p < .05$), and minority children spent more time on the site during the naturalistic phase ($r = .13, p < .05$).

Similarly, past research has shown that children are typically attracted to Cyberchase for the first time because of its entertainment value rather than their desire to seek out a program about mathematics (Fisch, 2005). In the present data, too, neither mathematics ability nor naming mathematics as a favorite subject was a significant predictor of viewing the Cyberchase television series. Only one such correlation emerged as significant, in that children who named math as a favorite subject were significantly more likely to visit the Cyberchase Web site ($r = .11, p < .05$). Thus, Cyberchase appeared to have similar reach among both “math kids” and non-“math kids.”

In contrast to the limited predictive power of the preceding demographic variables, the strongest and most consistent predictors of Cyberchase media use lay in children’s prior use of Cyberchase media. Just as the naturalistic data found that self-selected use of Cyberchase was consistent over time and across platforms (as discussed earlier), the correlation matrix revealed that children’s use of each Cyberchase medium (television and Web) prior to the study
significantly predicted their use of both types of media during the naturalistic phase. This was true in terms of both the number of times children used the television series and Web site, and the amount of time they spent.

Given this relationship among use of *Cyberchase* media, it is also reasonable to ask whether use of each medium might be related to their use of television and the Web in general. To that end, structural equation modeling was used to conduct a path analysis to examine the relationship between *Cyberchase* and *SpongeBob Squarepants* within each month of the naturalistic phase. The following figures present the relationships found between the two television series and between the two Web sites.

### Relationship between *Cyberchase* and *SpongeBob Squarepants*

<table>
<thead>
<tr>
<th></th>
<th>April</th>
<th>May</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cyberchase TV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SpongeBob TV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cyberchase Web</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SpongeBob Web</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cyberchase TV</em></td>
<td>.74</td>
<td>.07</td>
<td>.21</td>
<td>N.S.</td>
<td>.02</td>
</tr>
<tr>
<td><em>SpongeBob TV</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cyberchase Web</em></td>
<td>.34</td>
<td>.12</td>
<td>.34</td>
<td>.03</td>
<td>.13</td>
</tr>
<tr>
<td><em>SpongeBob Web</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As these figures illustrate, there were significant positive relationships between children’s viewing of the two television series in almost every month, and significant positive relationships between the two Web sites in every month. Thus, the choice to use educational or entertainment media was not an “either-or” dichotomy. Rather, children who engaged more with one media genre were likely to engage more with the other genre as well.

In sum, children’s use of *Cyberchase* media was predicted most consistently by their use of other media – their prior use of each type of *Cyberchase* media, and their use of entertainment media. Use of the *Cyberchase* television series was not predicted by either gender, ethnicity, mathematics ability, or naming math as a favorite subject, because *Cyberchase* reached all of these groups to a similar degree. However, girls, minority children, and children whose favorite subject was math all showed somewhat greater use of the *Cyberchase* Web site.
Educational Impact and Cross-Platform Learning

Having documented ways in which children used multiple Cyberchase media during the naturalistic phase, we now turn to experimental data that evaluated the educational benefits of children’s engagement with such media. We will consider these effects within three broadly defined areas: impact on mathematical problem solving, cross-platform learning from multiple media, and effects on children’s attitudes toward mathematics.

Overview of Results

Consistent with past research on the Cyberchase television series, use of Cyberchase resulted in significant gains on both the process of children’s mathematical problem solving and the sophistication of their solutions. Interestingly, learning from Cyberchase was not manifest in children’s simply doing a greater number of things while working on the tasks, but rather in their using a greater variety of strategies and heuristics, and in using those strategies and heuristics more effectively. As expected, more consistent effects were found for video plus online games than for either television or (especially) online games alone. Surprisingly, children in the DVD + Web group also showed consistently greater gains than children in the All Materials group, perhaps because of the demands of All Materials teachers’ having to make time for Cyberchase activities every day.

Effects on problem solving often appeared to be driven more by the TV series than by the online games, probably because television is designed to serve as the central component of Cyberchase, the television series presents models of successful problem solving in the context of compelling narratives, and the television series provides greater explanation of mathematical concepts than the games. Nevertheless, the online games provided a context for children to engage in rich mathematical reasoning that resembled the same sorts of progression that have been documented in formal classroom mathematics.

Data on children’s performance while playing 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.

Learning from Cyberchase

Past research has shown that, even in the absence of multiple media, sustained viewing of the Cyberchase television series can produce a significant impact on both the process of children’s mathematical problem solving and the sophistication of their solutions. As one might expect, these effects were found most consistently in tasks that were taken directly from television episodes that the children had seen, followed by near transfer and far transfer tasks, respectively.
(Fisch, 2003). With that in mind, the present study focused on far transfer, where ceiling effects were least likely to occur. It was designed to replicate the prior findings regarding far transfer from television, and extend them by determining whether transfer effects might arise more strongly through exposure to multiple media.

To that end, data from pretest-posttest problem-solving tasks (both paper-and-pencil and hands-on) were analyzed via a series of model-fitting analyses. Primarily, these consisted of general linear modeling, or GLM. The main questions addressed in each analysis were whether children who used Cyberchase media demonstrated greater pretest-posttest gains than children in the No Exposure group, and whether the gains observed among Cyberchase children differed as a function of which combinations of Cyberchase media they had used.

*Paper-and-pencil tasks:* As noted earlier, children were given two sets of pretest-posttest tasks, one concerning measurement (comparing several roads to find the longest or shortest route) and the other involving organizing data (predicting from data). To ensure that any observed differences among the experimental groups truly reflected effects of the treatment, our analysis controlled statistically for children’s reported use of the Cyberchase television series and Web site prior to the study.

The following figure presents pretest-posttest change in the sophistication of children’s solutions to the organizing data task. For details on what different solution scores represent, please see the sample coding scheme in Appendix C.

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3 A statistical note: Because intact classrooms of children (rather than individual children) were assigned to experimental groups, it was possible that apparent differences among experimental groups might actually be attributable to natural variation between the children’s classes. That is, the results could have been influenced by the effects of nested data. To rule out such effects, we planned to analyze the data via hierarchical linear modeling (HLM) that would control for nested data. However, preliminary analysis revealed that minimal variability existed between classrooms – too little for HLM analyses to be either possible or necessary. Thus, the data from the experimental phase were not nested data, and could be analyzed via GLM and other methods instead.

4 This level of control was possible for the paper-and-pencil tasks, because children completed paper-and-pencil tasks individually. However, we could not implement the same control for the hands-on tasks because children worked on hands-on tasks in groups of three, and the triads were not homogenous in terms of their use of Cyberchase prior to the study.
As this figure illustrates, there was a significant effect of Cyberchase ($F_{4,295} = 12.13, p < .0001$), in that all four Cyberchase groups produced more sophisticated solutions in the posttest, while the No Exposure declined from pretest to posttest ($t_{295} = 4.68, p < .0001$ for DVD Only vs. No Exposure; $t_{295} = 3.36, p < .001$ for Web Only vs. No Exposure; $t_{295} = 6.55, p < .0001$ for DVD + Web vs. No Exposure; $t_{295} = 2.18, p < .05$ for All Materials vs. No Exposure). For this reason, although few significant differences existed between the groups in the pretest, all of the Cyberchase groups scored significantly higher than the No Exposure group in the posttest ($t_{324} = 2.94, p < .005$ for DVD Only vs. No Exposure; $t_{324} = 2.35, p < .05$ for Web Only vs. No Exposure; $t_{324} = 7.92, p < .0001$ for DVD + Web vs. No Exposure; $t_{324} = 2.07, p < .05$ for All Materials vs. No Exposure). The effects of Cyberchase held constant across boys and girls of different levels of mathematics ability, and across children who either chose or did not choose math as their favorite subject.

With regard to comparisons among children who used different combinations of Cyberchase media, as expected, the DVD + Web group improved significantly more than both the DVD Only ($t_{295} = 2.93, p < .005$) and Web Only groups ($t_{295} = 3.63, p < .0005$). Surprisingly, however, the DVD Only and DVD + Web groups also improved significantly more than the All Materials group ($t_{295} = 2.31, p < .05$ and $t_{295} = 4.15, p < .0001$, respectively), even though the All Materials group had used more of the Cyberchase media.

In the measurement task, too, significant differences emerged among the treatment groups ($F_{4,293} = 2.68, p < .05$), but the results for this pair of tasks were less clear-cut. The following figure summarizes pretest-posttest change in the sophistication of children’s solutions to the measurement task. Again, detail on what solution scores represent can be found in the sample coding scheme in Appendix C.
In this case, the DVD Only and DVD + Web groups improved from pretest to posttest, while the Web Only group remained constant and the All Materials and No Exposure groups declined. (In fact, the All Materials group declined marginally more than the No Exposure group; $t_{293} = 1.80$, $p < .10$.) As a result, the DVD Only and DVD + Web groups both scored significantly higher than the No Exposure group in the posttest ($t_{321} = 2.06$, $p < .05$ and $t_{321} = 2.39$, $p < .05$, respectively). These effects held constant across boys and girls of different levels of mathematics ability, and across children who either chose or did not choose math as their favorite subject.

As in the organizing data task, an unexpected finding arose in that the DVD Only and DVD + Web groups both improved significantly more than the All Materials group ($t_{293} = 3.15$, $p < .005$ and $t_{293} = 2.18$, $p < .05$, respectively). The DVD Only group also improved marginally more than the Web Only group ($t_{293} = 1.64$, $p = .10$).

It is interesting to note that effects of Cyberchase emerged more strongly and consistently for organizing data tasks than for measurement, because past research on the Cyberchase television series also found more consistent effects for tasks that involved organizing data (Fisch, 2003). It is not clear whether educational content regarding organizing data was conveyed better than measurement, or whether children’s understanding of (and misconceptions about) measurement is simply more resistant to change.

**Hands-on tasks – process of problem solving:** Like the paper-and-pencil tasks, parallel sets of hands-on tasks were administered in the experimental pretest and posttest. Children worked on two sets of hands-on problem-solving tasks, one concerning measurement (“body math” and proportional reasoning) and the other dealing with organizing data (combinatorics and scheduling). Each task was comprised of two parts; in the first part, children attempted to solve the presented problem, and in the second, they were asked to abstract the process they had used.
to describe a procedure that could be used to solve other, similar problems in the future (similar to the output of the thought-revealing tasks described by Lesh et al, 2000, 2007).

As in the paper-and-pencil tasks, children’s solutions to each task were scored on the basis of their level of mathematical sophistication; data regarding children’s solutions will be presented in the “Hands-On Tasks – Sophistication of Solutions” section below. In addition, because researchers observed children’s process of mathematical problem-solving as they worked on each hands-on task, children were assigned a process score that reflected the number and variety of strategies and heuristics they used to address the problem (e.g., nonstandard measurement, trial and error).  

To illustrate the coding used for process and solutions, and children’s approaches to solving the problems, the table on pages 36-38 presents an example of one group of three children working on the posttest body math task. In this task, children pretend to be sculptors at a wax museum, who are asked to figure out the dimensions of Shaquille O’Neal’s body, based on a photo and outline of his footprint.

Model-fitting analyses were used to compare the experimental groups’ growth in each of these types of scores from pretest to posttest. Following the example in the table, we will present the results of these quantitative statistical analyses.

---

5 Note that, because children worked on these tasks in groups of three, the unit of analysis for hands-on tasks was the triad rather than the individual child. For each task, one process score and one solution score were assigned to the group of three children. Thus, the effective sample size for analyses of hands-on tasks was approximately one-third of the size of the sample for the paper-and-pencil tasks (which each child completed individually).
Sample Group Problem Solving (Shaquille O’Neal task)
Three students: 2 boys, one girl – “Max”, “Sam” and “Jeannie” (pseudonyms)

<table>
<thead>
<tr>
<th>Observations</th>
<th>Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part 1:</strong></td>
<td></td>
</tr>
<tr>
<td>Task is read to the students</td>
<td>Making a comparative observation about size of foot. (Estimate, approximate)</td>
</tr>
<tr>
<td>Shaq sent his print and picture, so we need</td>
<td>Students measure with different tools, with string (nonstandard), and with ruler (standard). They use standard units of measure (cm and inches) when measuring. (Measure: non-standard; Measure: standard)</td>
</tr>
<tr>
<td>to use those to be able to make Shaq’s statue the right size, all body parts need to match.</td>
<td></td>
</tr>
<tr>
<td>Jeannie: “Wow, his foot is bigger than his</td>
<td></td>
</tr>
<tr>
<td>picture”</td>
<td></td>
</tr>
<tr>
<td>Sam measures the foot with a piece of string</td>
<td></td>
</tr>
<tr>
<td>Jeannie and Max measure with rulers. They</td>
<td></td>
</tr>
<tr>
<td>discuss whether to measure in cm or inches. They</td>
<td></td>
</tr>
<tr>
<td>use inches and centimeter interchangeably when</td>
<td></td>
</tr>
<tr>
<td>discussing their measures. They get 12 inches</td>
<td></td>
</tr>
<tr>
<td>long and 4 ½ inches across. When discussing their</td>
<td></td>
</tr>
<tr>
<td>measures they then check the ruler again to</td>
<td></td>
</tr>
<tr>
<td>settle whether the measurement is in cm or</td>
<td></td>
</tr>
<tr>
<td>inches.</td>
<td></td>
</tr>
<tr>
<td>Sam: “Let’s times the length of this foot</td>
<td></td>
</tr>
<tr>
<td>with the length of the picture”</td>
<td></td>
</tr>
<tr>
<td>Jeannie: “What!? How is that going to do any</td>
<td></td>
</tr>
<tr>
<td>good?</td>
<td></td>
</tr>
<tr>
<td>Sam: “I don’t know”</td>
<td></td>
</tr>
<tr>
<td>Jeannie: “Okay” (grabs piece of paper and writes</td>
<td></td>
</tr>
<tr>
<td>6 ½ x 12) I don’t know how to time 6 and a half</td>
<td></td>
</tr>
<tr>
<td>times twelve.</td>
<td></td>
</tr>
<tr>
<td>Sam: (grabs calculator and punches in the</td>
<td></td>
</tr>
<tr>
<td>numbers) announces it’s 72 and a half</td>
<td></td>
</tr>
<tr>
<td>Max: “So he’s 7 foot tall”</td>
<td></td>
</tr>
<tr>
<td>Jeannie: “Can we cut out the foot?”</td>
<td></td>
</tr>
<tr>
<td>Max: (grabs scissors and cuts the outline of</td>
<td></td>
</tr>
<tr>
<td>Shaq’s foot)</td>
<td></td>
</tr>
<tr>
<td>While Max cuts the foot, Jeannie and Sam</td>
<td></td>
</tr>
<tr>
<td>measure themselves with the ruler. They</td>
<td></td>
</tr>
<tr>
<td>iterate the ruler and determine their height</td>
<td></td>
</tr>
<tr>
<td>by ‘folding’ the ruler (flipping it) upwards.</td>
<td></td>
</tr>
<tr>
<td>Jeannie measures Sam and announces he is</td>
<td></td>
</tr>
<tr>
<td>Making a comparative observation about size of</td>
<td></td>
</tr>
<tr>
<td>foot. (Estimate, approximate)</td>
<td></td>
</tr>
<tr>
<td>Students measure with different tools, with</td>
<td></td>
</tr>
<tr>
<td>string (nonstandard), and with ruler (standard).</td>
<td></td>
</tr>
<tr>
<td>They use standard units of measure (cm and</td>
<td></td>
</tr>
<tr>
<td>inches) when measuring.</td>
<td></td>
</tr>
<tr>
<td>They measure same object multiple times,</td>
<td></td>
</tr>
<tr>
<td>checking and rechecking each others’ measures.</td>
<td></td>
</tr>
<tr>
<td>(Measure: ruler)</td>
<td></td>
</tr>
<tr>
<td>Attempting to establish a math connection between</td>
<td></td>
</tr>
<tr>
<td>Shaq’s foot and picture (Trial and error/guess &amp; check)</td>
<td></td>
</tr>
<tr>
<td>Questioning reasonableness (Reasonableness)</td>
<td></td>
</tr>
<tr>
<td>Use paper-pencil and calculator to compute</td>
<td></td>
</tr>
<tr>
<td>(Calculate)</td>
<td></td>
</tr>
<tr>
<td>Manipulate and transform objects</td>
<td></td>
</tr>
<tr>
<td>(Manipulate: change object)</td>
<td></td>
</tr>
<tr>
<td>Use ruler to measure their own heights</td>
<td></td>
</tr>
<tr>
<td>(Measure: ruler)</td>
<td></td>
</tr>
</tbody>
</table>
4 1/2 rulers tall. Measures herself the same way and determines she is 4 rulers tall.
Max: “Why are we measuring ourselves?”
Sam: I don’t know
Max: Man we’re wasting paper! Killing trees! You should make Shaq come here!

Sam: I wonder how big my foot is compared to his?
Everyone places their foot on the print to compare
Jeannie: I’m probably by his waist

*When asked to share what they have been able to figure out so far:*
Students say that the foot length is 12 inches long, and that in order to calculate the height they multiplied 12 by either 6 or 7, so the height is about 7 feet tall. They attempt to show this height by saying that it’s about Sam’s height and Jeannie’s height put together. So basically length of the foot times 6 (which they do say is 72, they use the 7 to claim that the height is 7 feet tall). They say the reason to multiply by 6 or 7 is because that’s the height in the picture. When pressed why they were multiplying by the height of the picture. They were not really able to explain this. Sam says I don’t know because we’ve seen that been done before.

**Reasonableness (Reasonableness)**

**Comparative measuring (Estimate)**

**Accurate measurement of foot length**

**Calculate actual height (erroneously) by multiplying length of actual foot by measure of Shaq’s height in the picture.**

**Recalling information (Recalling information)**

Part 2:

*Need your help in doing what you just did to figure out how to work from a footprint and a photograph to make a statue – for anybody, not just Shaq’s*

Students do a bit more talking about what they did and organize their ideas. Max keeps questioning the wisdom of Shaq not sending his actual height measurements.

Students wrote and shared the following steps to follow in order for the sculptor to
make anyone’s statue when they send in their footprint and their picture.

1. Measure the width and the length of the shoe print and record it. That helps you make their foot.
2. Measure the picture’s height.
3. Times it (picture’s height) and the length of the shoe
4. Divide the answer by 7

As an aside, Jeannie says you could also measure the picture’s arms and legs.

Reasonableness

(Reasonableness)

Writing in note pad
(Write: list, table, chart)

Inaccurate ‘algorithm’ for calculating a person’s actual height given their footprint and a picture of themselves.

Solution score:

Part 1: 5 points - Inference about height based on incorrect body math

Award 3 points for at least one instance of using standard or nonstandard measurement accurately to document size of footprint, handprint, or hat (within ½” margin of error). And, 2 points for at least one inaccurate use of body math to infer size of other body parts or overall height (without any accurate uses of body math at other points during the task).

Part 2: 4 points – Inaccurate attempt to use body math

Award 4 points for at least one inaccurate or incomplete attempt at general principle that uses body math to draw inferences about other body parts (e.g., “Measure the foot and multiply by 10 to figure out how tall the person is,” “Measure your size [relations] and the other person’s, and if it’s the same for you, it’ll probably be the same for the statue”), without any accurate attempts.

Model-fitting analyses regarding both sets of hands-on tasks revealed that learning from Cyberchase was not simply manifest in children’s doing a greater number of things while working on the tasks ($F_{4,15} = 2.01$, N.S. for organizing data tasks, and $F_{4,21} = 0.8$, N.S. for body math tasks). Rather, the effects of Cyberchase appeared in children’s using a greater variety of strategies and heuristics from pretest to posttest, and in using those strategies and heuristics more effectively.

The following figure presents pretest-posttest change in children’s process scores for the hands-on organizing data tasks. The scores in this figure represent the variety of strategies and heuristics children used, via the number of unique heuristics they employed (i.e. not counting duplication if a triad used the same type of heuristic more than once).
As this figure suggests, a significant effect of Cyberchase emerged \((F_{4,19} = 4.21, p = .01)\), in that the DVD Only and DVD + Web groups both increased significantly more than the No Exposure group in the variety of problem-solving heuristics they applied to the task \((t_{19} = 3.31, p < .005)\) for DVD Only vs. No Exposure; \(t_{18} = 2.97, p < .01\) for DVD + Web vs. No Exposure). In the posttest, the DVD + Web group used a significantly greater variety of heuristics than the No Exposure group \((t_{17} = 2.10, p < .05)\).

For this reason, although few significant differences existed between groups in the pretest, all of the Cyberchase groups scored significantly higher than the No Exposure group in the posttest \((t_{324} = 2.97, p < .005)\) for DVD Only vs. No Exposure; \(t_{324} = 2.19, p < .05\) for Web Only vs. No Exposure; \(t_{324} = 7.88, p < .0001\) for DVD + Web vs. No Exposure; \(t_{324} = 2.13, p < .05\) for All Materials vs. No Exposure). The effects of Cyberchase held constant across boys and girls of different levels of mathematics ability, and across children who either chose or did not choose math as their favorite subject.

Turning to comparisons among children who used various combinations of Cyberchase media, the DVD Only and DVD + Web groups produced significantly greater gains than either the Web Only \((t_{20} = 2.34, p < .05)\) for DVD Only vs. Web Only; \(t_{18} = 2.32, p < .05\) for DVD + Web vs. Web Only) or All Materials groups \((t_{17} = 2.13, p < .05)\) for DVD Only vs. All Materials; \(t_{17} = 2.12, p < .05\) for DVD + Web vs. All Materials). In the posttest, the DVD Only, DVD + Web, and All Materials groups all used a greater variety of heuristics than the Web Only group did \((t_{18} = 2.30, p < .05)\) for DVD Only; \(t_{17} = 3.05, p < .01\) for DVD + Web, and \(t_{19} = 2.25, p < .05\) for All Materials).

As in the paper-and-pencil tasks, differences between users and non-users of Cyberchase emerged more strongly in organizing data tasks than in measurement tasks. The following figure
presents pretest-posttest change in process scores for the body math tasks (again reflecting the unique heuristics that children used, without counting duplication).

As this figure suggests, the overall effect of treatment group on pretest-posttest change was not strong enough to reach statistical significance ($F_{4,22} = 1.37$, N.S.). However, within groups, the DVD + Web group was the only group that used a significantly greater variety of heuristics in the posttest than they had used in the pretest ($t_4 = 3.35$, $p < .05$). As a result, in the posttest, the DVD + Web group used a significantly greater variety than the No Exposure group ($t_{17} = 2.10$, $p = .05$).

In addition, the DVD + Web, DVD Only, and All Materials groups all used a significantly greater variety than the Web Only group in the posttest, although no such differences appeared in the pretest ($t_{17} = 3.05$, $p < .01$; $t_{18} = 2.30$, $p < .05$; and $t_{19} = 2.25$, $p < .05$, respectively).

Together, then, the organizing data tasks suggest that children used a greater variety of strategies and heuristics as a result of their use of Cyberchase. The measurement tasks provide some additional support for this conclusion in the case of the DVD + Web group. Given this trend, it would be natural to ask which heuristics were primarily responsible for this greater variety. To find out, separate model-fitting analyses were conducted for each of the heuristics in the coding scheme. These analyses revealed significant or marginally significant effects regarding eight heuristics. Most of these effects did not form a coherent trend across heuristics. However, two of them were meaningful:

- **Reasonableness (i.e. reconsiders own ideas):** A marginally significant overall effect was found for this heuristic in the measurement task ($F_{4,341} = 2.01$, $p < .10$). All four
Cyberchase groups were either significantly or marginally more likely to evaluate their own ideas in the posttest, whereas the No Exposure group showed no change.

- Recalls Cyberchase (i.e. spontaneously recalls relevant information from Cyberchase and labels it as such): A marginally significant effect was found for this heuristic in the measurement task ($F_{4,339} = 2.12, p < .10$). In the posttest, all four Cyberchase groups explicitly (and spontaneously) recalled information from Cyberchase to help them with the task, whereas the No Exposure group did not.

Thus, in the posttest, children who used Cyberchase were somewhat more likely to question and reconsider their own ideas as they worked on the measurement task. This is consistent with our qualitative observations that, in the posttest, Cyberchase users employed top-down approaches to problem solving and demonstrated persistence when one attempt at a solution did not succeed (as will be discussed later, in the section on “Qualitative Observations – Hands-On Problem Solving”). It is not surprising that Cyberchase users explicitly recalled information from Cyberchase more often than the No Exposure group (although even the No Exposure group could have done so, if they had ever encountered Cyberchase outside the context of the study). However, the fact that approximately one-third of users spontaneously referred to Cyberchase while working on posttest tasks supports the conclusion that the observed pretest-posttest differences were indeed attributable to their experience with Cyberchase.

As noted, the remaining significant or marginally significant differences in use of individual heuristics did not form a cohesive trend across the heuristics:

- Manipulate: Change objects (e.g., build a nonstandard measuring device, make notations directly on hands-on materials): A significant effect was found for this heuristic in the measurement task ($F_{4,341} = 5.30, p < .0005$). The All Materials group increased in their use of the heuristic from pretest to posttest, while the No Exposure and DVD Only groups used it less often in the posttest.
- Manipulate: Use objects (e.g. use one object to represent another, manipulate cards to physically make combinations): Significant effects were found regarding this heuristic in both sets of tasks ($F_{4,344} = 2.41, p < .05$ for organizing data, and $F_{4,341} = 2.79, p < .05$ for measurement). In the posttest organizing data task, the DVD Only group used this heuristic significantly more than the No Exposure group, and the DVD + Web group used it significantly more than the Web Only group. In the measurement task, the All Materials group used this heuristic less from pretest to posttest, while the No Exposure group used it more in the posttest.
- Gather information (e.g., observing or studying hands-on materials): Significant effects were found regarding this heuristic in both sets of tasks ($F_{4,341} = 6.62, p < .0001$ for organizing data, and $F_{4,344} = 2.01, p < .10$ for measurement). In both cases, the DVD + Web group used this heuristic either significantly or marginally more in the posttest than the pretest. The No Exposure showed a similar gain in the measurement task, but did not change in the organizing data task. The All Materials group spent less time gathering information in the measurement task posttest, and the Web Only group showed a marginally significant decrease in the organizing data task.
• **Write:** List (i.e. record data in a list to keep track of it): A significant effect was found for this heuristic in the organizing data task ($F_{4,344} = 3.84, p < .005$), in that the All Materials group wrote lists more often from pretest to posttest, while the DVD Only group showed a small decrease.

• **Estimate:** A marginally significant effect was found for this heuristic in the measurement task ($F_{4,341} = 2.00, p < .10$). The Web Only group used significantly more estimation in the posttest than in the pretest.

• **Look for patterns (e.g., in proportional relationships among body parts):** A significant effect was found for this heuristic in the measurement task ($F_{4,341} = 2.20, p < .0005$), in that the Web Only group used it slightly less in the posttest, whereas all of the other groups increased.

**Hands-on tasks – sophistication of solutions:** As noted earlier, children’s solutions to each hands-on task were comprised of two parts; the first part asked them to solve the presented problem, and the second part asked them to abstract their work to describe a way in which other, similar problems could be addressed in the future. The sophistication of the children’s answers to each part was scored separately, and also pooled into a total solution score that reflected the sophistication of their solution to the task as a whole.

The following figures show pretest-posttest change in children’s solutions to the two sets of tasks.
In both sets of tasks, all five treatment groups showed improvement from pretest to posttest. As a result, neither set of tasks elicited significant overall differences among the treatment groups ($F_{4,20} = 1.27, n.s.$ for organizing data; $F_{4,19} = 1.71, n.s.$ for measurement). However, pairwise comparisons in the organizing data tasks revealed that the DVD Only group improved significantly more than the No Exposure group from pretest to posttest ($t_{21} = 2.17, p < .05$).

In addition, finer-grained analyses revealed several other significant effects that favored some or all of the groups that used Cyberchase. In the organizing data tasks, within-group analysis found that the DVD Only and Web Only groups both showed significant gains from pretest to posttest ($t_6 = 4.21, p < .01$, and $t_{11} = 2.20, p = .05$, respectively). The same was true for the All Materials group, although their gains were only marginally significant ($t_5 = 2.18, p < .10$). Neither the No Exposure nor (surprisingly) the DVD + Web group showed significant gains ($t_6 = 0.96, n.s.$, and $t_{12} = 1.61, n.s.$, respectively). In the posttest, the DVD + Web and All Materials groups both produced marginally more sophisticated solutions than the No Exposure group ($t_{21} = 1.97, p < .10$, and $t_{23} = 1.68, p < .10$, respectively).

In the measurement tasks, the DVD + Web group was the only one whose within-group gains were large enough to be statistically significant ($t_6 = 2.85, p < .05$). As a result, in the posttest, the DVD + Web group produced significantly more sophisticated solutions than the No Exposure group ($t_{20} = 2.49, p < .05$). The posttest solutions produced by the DVD Only and All Materials groups were also somewhat more sophisticated than the No Exposure group’s, although this difference was only marginally significant ($t_{21} = 1.89, p < .10$, and $t_{22} = 1.82, p < .10$, respectively).

In both sets of tasks, effects on solution were centered primarily in the second part of the task, in which children had to abstract their work to describe a way in which other, similar problems could be addressed in the future. In the organizing data tasks, within-group analysis found that three out of the four Cyberchase groups improved significantly on this part of the task ($t_{12} = \ldots$)

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3.95, \( p < .005 \) for DVD Only; \( t_{25} = 2.52, p < .05 \) for Web Only, and \( t_{14} = 3.43, p < .005 \) for All Materials), whereas the No Exposure and DVD + Web groups did not (\( t_{26} = 0.74, \text{n.s.} \) for No Exposure, and \( t_{17} = 1.50, \text{n.s.} \) for DVD + Web). Similarly, in the measurement tasks, all four Cyberchase groups improved significantly from pretest to posttest (\( t_{26} = 3.76, p = .001 \) for DVD Only; \( t_{27} = 2.65, p = .01 \) for Web Only; \( t_{19} = 3.26, p < .005 \) for DVD + Web; and \( t_{20} = 3.03, p < .01 \) for All Materials), whereas the No Exposure group did not (\( t_{26} = 0.99, \text{n.s.} \)). The emergence of significant effects in this part of the tasks is especially interesting, both because this part of the tasks was closest to the design of the thought-revealing activities discussed by Lesh et al. (2000, 2007) and others, and because its focus on describing a process to be applied to future problems is particularly relevant to transfer of learning.

If we consider the data regarding process and solution scores (both hands-on and paper-and-pencil) together, three noteworthy trends are evident. First, there were numerous instances in which one or more of the groups that used Cyberchase outperformed the No Exposure group, speaking to the educational power of Cyberchase as a whole. Second, as expected, effects often appeared more consistently in the DVD + Web group than in either the DVD Only or Web Only groups, suggesting greater learning from multiple media than from either medium alone. Surprisingly, though, 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). Although we cannot be certain, we believe that the less consistent performance of the All Materials group may have been influenced by attitudinal cues in teachers’ behavior in response to the demands of having to make time for Cyberchase activities every day.

Third, effects on problem solving often appeared to be driven more by the television series than by the online games, as seen in more consistent effects in the DVD Only group (and other groups that viewed the television series) than in the Web Only group. We suspect that this is due to the fact that television is designed to serve as the central component of Cyberchase, embeds mathematical content and successful problem solving in the context of compelling stories, and provides greater explanation of mathematical concepts than the games (which allow children opportunities to exercise skills, but present less overt explanation). We will return to all three of these points in the Conclusions and Implications section at the end of this report.

**Problem solving during online games:** Although the Cyberchase television series produced stronger pretest-posttest effects than the online games, this is not to say that the online games were without educational value. Elsewhere, we have drawn on pilot data gathered in support of the present study to examine children’s mathematical problem-solving while playing several online Cyberchase games (Fisch et al., in press). Analyses of both in-person observations and online tracking data of children’s clicks pointed to the games’ providing a context for rich mathematical reasoning. While playing Cyberchase online games, children engaged in processes of problem solving that resembled the sorts of processes that past research has documented during mathematical problem solving in formal education.

Just as one might expect in offline mathematical reasoning, we found a range of sophistication in the mathematical strategies that children used while playing the games. Moreover, parallel to research on classroom mathematics (e.g., Lesh et al., 2000) and findings within the developmental literature on children’s strategy usage (e.g., Siegler, 2007), those children who
used more sophisticated strategies often did not apply them immediately. Rather, they engaged in cycles of problem solving that began with less sophisticated strategies and progressed to more sophisticated approaches when necessary.

This finding was confirmed in the present, full study. For example, in the full study, 145 children played the game Railroad Repair at least once. While playing the game for the first time, 68% of these children showed evidence of at least one use of the highest-level strategy in our coding scheme, 28% progressed as far as a mid-level strategy, 1% never moved beyond the most basic strategy, and 2% did not employ any of these strategies (and, as a result, did not provide any correct answers). Yet, despite the fact that 96% of the children used more sophisticated strategies at some point during the game, all but two of the 145 children used the most basic strategy at the beginning of the game. Thus, parallel to classroom reasoning, even those children who were capable of more sophisticated reasoning typically began by using a more basic strategy (perhaps in the interest of efficiency), and the level of their reasoning evolved over the course of gameplay, in response to the increasing demands of the game.

*Qualitative observations – hands-on problem solving:* Whereas quantitative, statistical analysis has great value in providing the methodological rigor necessary to evaluate children’s learning, it also can be somewhat limited in its ability to capture the flavor of such learning. To better understand the nature of the learning that produced the significant effects documented above, we now turn to qualitative observations of children’s hands-on problem solving. The goal of this section is to describe the nature of the pretest-posttest changes observed in children’s problem solving, and to suggest several plausible conjectures about possible causes of these changes.

To appreciate the significance of the changes that were observed, it is important to go beyond wishful thinking and recognize the current state of research on problem solving in mathematics education. Every ten years, the National Council of Teachers of Mathematics publishes a Handbook of Research in Mathematics Education (Lester, 2007); the 2007 edition was edited by Frank Lester, one of the foremost, nationally prominent researchers focusing on mathematical problem solving. As plans were being formulated for this huge project, Lester noted that research on problem solving has declined significantly during the past decade. So, he specifically asked the authors of the chapter on problem solving (i.e., Richard Lesh and Judi Zawojewski) to analyze these trends, to explain the most significant causes and trends, and to describe promising new directions for future research. The following facts were noted.

- Polya-style problem solving heuristics – such as *draw a picture*, *work backwards*, *look for a similar problem*, or *identify the givens and goals* - have long histories of being advocated as important abilities for students to develop (e.g., Polya, 1957). But, it is not at all clear what it mean to “understand” them. Such strategies clearly have descriptive power. That is, experts often use such terms when they give after-the-fact explanations of their own problem solving behaviors - or those of other people that they observe. Nonetheless, the state of research on mathematical problem solving has not changed significantly since Begel’s comprehensive review of the literature in 1979:

  “There is little evidence that general processes that experts use to describe their past problem solving behaviors should also serve well as prescriptions to guide novices’ next-
steps during ongoing problem solving sessions…[N]o clear cut directions for mathematics education are provided by the findings of these studies. In fact, there are enough indications that problem-solving strategies are both problem- and student-specific often enough to suggest that hopes of finding one [or a few strategies] which should be taught to all [or most students] are far too simplistic.” (Begel, 1979, p. 145)

• Similarly, Schoenfeld’s (1992) review of the literature again concluded that attempts to teach students to use general problem-solving strategies have not been successful. Schoenfeld noted that Polya’s descriptive processes are really more like names for large categories of processes rather than being well defined processes in themselves. So, wishful thinking notwithstanding, short lists of descriptive processes tend to be too general to be useful; yet, long lists of prescriptive processes tend to become so numerous that knowing when to use them becomes the heart of understanding them.

In the light of the preceding facts about the state of research on mathematical problem, the point that is perhaps most noteworthy from this Cyberchase assessment project is that students did in fact improve significantly in their problem solving capabilities. Furthermore, an on-site visitor to our research sites would have provided evidence that would be even more impressive than the results that are clear in the project’s statistical analyses.

In the observations that follow, special attention will be given to students’ performances on two pairs of 20-minute, hands-on tasks that were used as pre- and posttest items. As discussed in the Method section earlier in this report, the pretest problems were called the Ping Pong and the Detective tasks; and the posttest problems were called the Soccer and the Big Foot tasks (or Shaquille O’Neal task). All four problems are junior versions of model-eliciting activities that have been used in a number of research projects investigating models and modeling abilities for students from elementary school through high school, college, and graduate students – as well as in-service and pre-service teachers, and professionals in fields such as engineering were mathematical thinking is an important component of expertise (Lesh & Doerr, 2002; Lesh, Hamilton & Kaput, 2007). Such activities were designed explicitly to be simulations of “real life” problem solving situations – and to focus on elementary-but-deep mathematical concepts and abilities that are seldom addressed on short-answer standardized tests. Consequently, such activities are especially useful for identifying high-ability students who seldom emerge as being highly capable using traditional tests.

Of course, doing “bean counts” of process objectives is problematic for a variety of reasons. For instance, it often was difficult for coders to determine whether a single process was used several times, or whether these should be counted as different instances of process use. Similarly, simple counts do not take into account the fact the different processes should perhaps be given different weights. Nonetheless, the fact that (as noted earlier) Cyberchase users demonstrated significantly greater growth than non-users in both the variety of heuristics they used and the sophistication of their solutions suggests that what changed from early activities to later activities was the size, or power, or effectiveness of processes used – and not gross number of processes-strategies-ideas used.
What appeared to explain these differences in effectiveness with which processes, strategies, and ideas were used? For the researchers and research assistants who were on-site for the start-of-project and end-of-project problem solving sessions, a number of changes were obvious in children’s behaviors. In Indiana, some of these behaviors were especially striking because most of the research team was also working on a separate research project in which undergraduate students and graduate students were observed working on model-eliciting activities that were very similar to those that were used with children in the *Cyberchase* project. So, for these research assistants, the following facts were obvious in posttest problem solving performance for children who had participated in the project:

- *The children were remarkably effective at working well in groups.* For example, even compared with more mature students at the university, a variety of diverse and appropriate roles were adopted by children in the groups; few students were left out; and roles often shifted appropriately when needs arose. In doing so, the children often referred to *Cyberchase* stories that they had watched – and to roles played by the *Cyberchase* characters.

- *The children often actually engaged in “top down” planning!* By contrast, no instances of such behavior were recorded for problem solving sessions at the start of the project. That is, for posttest problem-solving activities, before charging ahead on a plan (with little reflection), the children often did something akin to “brainstorming” and formulated a general plan before they proceeded along some presumed solution path. *This is very uncommon behavior* – even among students we have observed at the university. And, it seemed to be the most important single factor that explained performance increases for students who viewed the *Cyberchase* television series. Again, references to *Cyberchase* stories seemed to provide the most obvious stimulus and guide for these behaviors.

- *The children persevered.* They were not disturbed if their first way of thinking about the problem didn’t work, and they assumed from the start that the problem was not going to be solved in a couple of minutes. Again, references to *Cyberchase* episodes seemed to provide models of the kinds of behavior that would be needed.

Whereas programs that aim at increasing problem solving performance traditionally focus on teaching processes, strategies, heuristics, beliefs, dispositions, or attitudes that are embodied in rules – in the hopes that students will later connect these rules to relevant concepts needed to solve problems – the primary factor that seemed to explain success on this project was “stories.” If one takes seriously the research of researchers like Lakoff, Schank, or Lesh, then this should not be surprising. In virtually every field where researchers have investigated differences between effective problem solvers and those who are less effective, it has become clear that effective problem solvers not only *do* things differently, but they also *see* (or interpret) things differently. Relevant theories have described these interpretation systems have been described using the language of models, metaphors, stories, or scripts. But, in any case, they cannot be summarized as fact, a process, or a rule. And, they are not likely to be assessed by standardized tests.

Did these activities allow us to document the abilities of students whose potential had not previously been apparent in the context of traditional word problems of the type emphasize in
textbooks and tests? All we can say from the current study is that most of the participating teachers believed that this was the case. That is, we often recorded comments from teachers who said that “I’ve never seen [Johnny or Jenny] do this well before in math.” Similarly, children often commented that “Different characters contributed in different ways [to solutions in Cyberchase episodes].” (For further comments from teachers and children, see the “Perceptions of Cyberchase and Learning” section later in this report.) Again, the adoption of an effective problem-solving persona did appear to be reducible to a pledge of allegiance to some easily stated belief, habit of mind, disposition, or rule of behavior.
Cross-Platform Learning

Earlier, we presented evidence of transfer of learning in terms of children’s ability to apply the sorts of problem-solving strategies and heuristics modeled in *Cyberchase* to new problems in the posttest (resulting in stronger pretest-posttest gains among users of *Cyberchase* than among non-users). This sort of transfer is clearly an important part of the impact of any media-based informal education project, whether the project employs several forms of media or just one.

From the standpoint of cross-platform learning, however, we were also interested in how learning from one medium might interact with learning from another. In this respect, we were interested, not only in how learning from one medium might transfer to a posttest assessment, but also in how it might transfer into children’s engagement and performance while interacting with (and learning from) a different form of educational media. Specifically, we used the online tracking data discussed above to compare performance in three online *Cyberchase* games between children who only played the games (i.e. the Web Only group) and those who also used other forms of *Cyberchase* media (i.e. the All Materials group). Parallel to the analysis of hands-on tasks discussed earlier, our analysis of online tracking data focused on two aspects of performance in the games: strategy scores (reflecting the sophistication of the strategies children used while playing the game) and solution scores (equivalent to the number of correct responses that children produced in each game). For further information about these scores, see the coding schemes presented in Appendix G.

The following figure compares the strategy scores received by the All Materials and Web Only groups in each of the three games.
On average, children in the All Materials group applied significantly more sophisticated strategies than the Web Only group while playing each of the three games ($t_{109} = 3.04, p < .005$ for Railroad Repair; $t_{68} = 3.01, p < .005$ for Sleuths on the Loose; and $t_{89} = 4.82, p < .0001$ for Pour to Score).

As a result, these children also produced more correct responses in two of the three games, as seen in the following figure.

![Performance in online games: Solution score](image)

On average, the All Materials group provided significantly more correct responses than Web Only group while playing Railroad Repair ($t_{93} = 2.72, p < .01$) and Pour to Score ($t_{92} = 3.96, p < .0001$). The effect on solution scores in Sleuths on the Loose was not strong enough to achieve significance ($t_{68} = 1.282, n.s.$).

Taken together, this pattern of online effects points to a significant strength of cross-platform learning: The lessons learned from one medium can be applied, not only to enrich children’s general knowledge, but also to enrich children’s experience while they are in the process of learning from a second medium. These effects are particularly intriguing in the case of Railroad Repair, because its mathematical content (adding decimals) was not aligned closely with any of the television episodes or hands-on games in the treatment, although the same sorts of underlying problem-solving strategies and systematic thinking could be used. We shall return to this point in the Conclusions and Implications section below.
Impact on Attitudes Toward Mathematics and Problem Solving

Overview of Results

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, 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.

Attitude

As described in the Method section, several measures were used to investigate the effects of multiple Cyberchase media on children’s attitudes toward mathematics and problem solving. One pair of paper-and-pencil attitude scales focused on children’s interest and confidence in engaging in a variety of mathematical activities. Motivation was assessed via a paper-and-pencil measure that addressed orientation toward engaging in challenging mathematics activities (mastery vs. performance), and online tracking data provided a behavioral means for gauging motivation toward engaging in math-based games.

In comparison to the problem-solving data presented earlier, fewer significant effects emerged regarding attitude. However, some significant effects did appear, as we shall see.

Interest and confidence: Interest and confidence scales were administered in both the pretest and posttest. Children were asked to rate their interest and confidence in a variety of mathematical and non-mathematical tasks that fell into four categories (and subscales): Cyberchase math (i.e. mathematics that was presented in Cyberchase materials during the treatment), non-Cyberchase math (i.e. out-of-school mathematics that did not appear in any of the Cyberchase materials in the treatment), school math (e.g., solving blackboard problems or studying for math tests), and non-math (i.e. non-mathematical activities, such as exploring the history of one’s home town). For each activity mentioned in the scale, children rated their interest on a five-point scale (with the most positive response option coded as 5), and rated their confidence on a parallel five-point scale.

The following tables present children’s mean responses regarding interest and confidence.
Interest: Mean scores

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<tr>
<th></th>
<th>Control</th>
<th>DVD Only</th>
<th>Web Only</th>
<th>DVD + Web</th>
<th>All Materials</th>
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<td>Post</td>
<td>Pre</td>
<td>Post</td>
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Confidence: Mean scores

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<th>Control</th>
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<th>Web Only</th>
<th>DVD + Web</th>
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<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>School math</td>
<td>4.76</td>
<td>4.59</td>
<td>4.25</td>
<td>4.50</td>
<td>4.31</td>
</tr>
<tr>
<td>Cyberchase math</td>
<td>4.01</td>
<td>3.74</td>
<td>3.62</td>
<td>3.74</td>
<td>3.61</td>
</tr>
<tr>
<td>Non-Cyberchase math</td>
<td>3.72</td>
<td>4.06</td>
<td>3.59</td>
<td>3.91</td>
<td>3.70</td>
</tr>
</tbody>
</table>

Note: By chance, during the pretest, too few children in the DVD + Web group responded to the non-Cyberchase math items to allow for statistical analysis. Thus, this cell has been omitted from each table.

In interpreting these data, it is helpful to consider the results obtained from past research regarding the effects of other mathematics-based television series. Some past studies have found sustained viewing of series such as Square One TV to result in increased attitudes (e.g., Debold et al., 1990), but others have found viewing of series such as Futures to produce a different sort of effect: helping to sustain children’s positive attitudes toward mathematics while nonviewers’ attitudes declined (Research Communications Ltd., 1992; cf. Crane et al., 1994).

As the above tables illustrate, the latter type of effect was evident here. In almost every dimension, the No Exposure group’s interest and confidence declined from pretest to posttest, and the same was true for non-mathematics activities among all of the treatment groups. By contrast, in all of the mathematics-related dimensions, the four Cyberchase groups’ ratings remained fairly constant from pretest to posttest. This difference between users and non-users of Cyberchase, although evident throughout the data from both scales, achieved statistical significance only for interest in school math ($F_{4.267} = 6.91, p < .0001$) and marginal significance for confidence in school math ($F_{4.270} = 2.16, p < .10$).

Model-fitting analyses revealed that the No Exposure group declined significantly more than all of the Cyberchase groups in interest in school math ($t_{267} = 4.54, p < .0001$ for DVD Only; $t_{267} = 4.16, p < .0001$ for Web Only; $t_{267} = 2.46, p = .01$ for DVD + Web; and $t_{270} = 3.80, p < .0005$ for All Materials). Similarly, the No Exposure group also declined either significantly or marginally more than all four Cyberchase groups in confidence in school math ($t_{270} = 2.38, p < .05$ for DVD Only; $t_{70} = 1.71, p < .10$ for Web Only; $t_{270} = 2.81, p = .005$ for DVD + Web; and $t_{270} = 1.91, p < .10$ for All Materials).
Motivation: No significant effects were found in our paper-and-pencil measure of orientation toward motivation, in any of the three contexts used in the measure: classroom mathematics ($\chi^2_8 = 3.21, n.s.$), video games ($\chi^2_8 = 6.62, n.s.$), or out-of-school mathematics ($\chi^2_8 = 2.80, n.s.$).

However, significant effects did emerge in a behavioral measure of motivation that employed data from the online Cyberchase games to assess the number of children who were sufficiently motivated to continue playing a math-based game even after they reached the end of the game. As discussed in the Method section, it is typically difficult to measure motivation via variables such as time on task, because such measures confound the effects of ability and motivation. In the present study, however, we overcame this challenge by restricting our motivation analysis to only those children who reached the end of each online game; since all of the children in the subsample had sufficient ability to successfully complete the game, continuing to play beyond the end of the game was a clear indicator of motivation. Thus, by comparing children who only played the games (the Web Only group) to children who used multiple Cyberchase media (the All Materials group), we could determine whether the use of multiple media increased children’s motivation to engage further in mathematics-based games.

The following tables present the percentage of children in the All Materials and Web Only groups who chose to either stop or continue playing once they reached the end of a game.

### Railroad Repair game

<table>
<thead>
<tr>
<th></th>
<th>Continue beyond end</th>
<th>Do not continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Materials</td>
<td>32%</td>
<td>68%</td>
</tr>
<tr>
<td>Web only</td>
<td>8%</td>
<td>92%</td>
</tr>
</tbody>
</table>

### Pour to Score game

<table>
<thead>
<tr>
<th></th>
<th>Continue beyond end</th>
<th>Do not continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Materials</td>
<td>31%</td>
<td>69%</td>
</tr>
<tr>
<td>Web only</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Sleuths on the Loose game

<table>
<thead>
<tr>
<th></th>
<th>Continue beyond end</th>
<th>Do not continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Materials</td>
<td>12%</td>
<td>88%</td>
</tr>
<tr>
<td>Web only</td>
<td>15%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Chi-square analysis revealed that, in two of the three games, children in the All Materials group were more likely to continue playing beyond the end of the game than children in the Web Only group ($\chi^2_1 = 8.09, p < .005$ for Railroad Repair; $\chi^2_1 = 7.90, p = .005$ for Pour to Score; and $\chi^2_1 = 0.10, n.s.$ for Sleuths on the Loose). Thus, it appeared that children who used multiple Cyberchase media were more motivated to engage in a fun, mathematical activity that featured the same characters and world. We believe that this finding holds important implications for the
role of multiple media in contributing to children’s interest in academic subjects, especially from the perspective of Hidi and Renninger’s (2006) four-phase model of interest development. We will return to this point in the Conclusions and Implications section.
Perceptions of Cyberchase and Learning: Supplementary Teacher and Child Interviews

Following the experimental posttest, supplemental interviews were conducted with participating children and teachers, to help us interpret the data and understand the effects found in the study. These interviews focused on Cyberchase itself: their experiences with and reactions to the materials, and what (if anything) they believed children learned from Cyberchase.

Please note that, because these interviews concerned Cyberchase itself, they could not be conducted with children in the No Exposure group, who had not used the materials.

*Perceptions of learning:* The following table shows the percentage of children in each of the treatment groups who believed that they had or had not learned from Cyberchase.

<table>
<thead>
<tr>
<th>Percentage of children who believed they:</th>
<th>All Materials</th>
<th>DVD + Web</th>
<th>DVD Only</th>
<th>Web Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learned from Cyberchase</td>
<td>90%</td>
<td>100%</td>
<td>96%</td>
<td>70%</td>
</tr>
<tr>
<td>Did not learn</td>
<td>10%</td>
<td>0%</td>
<td>4%</td>
<td>30%</td>
</tr>
</tbody>
</table>

As this table shows, the vast majority of children in all four Cyberchase groups felt that they had learned from Cyberchase. However, just as the experimental data found that impact was often smaller in the Web Only group, significantly fewer children in this group believed they had learned (although most of the Web Only children said they learned as well). More than 90% of the children in each of the other groups believed they had learned from Cyberchase, as opposed to 70% of the children in the Web Only group ($\chi^2 = 18.80, p < .001$).

Differences also appeared in children’s accounts of what they thought they had learned from Cyberchase, as shown in the following table.

<table>
<thead>
<tr>
<th>Number of children who believed they learned:</th>
<th>All Materials</th>
<th>DVD + Web</th>
<th>DVD only</th>
<th>Web only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Math&quot; in general</td>
<td>17</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Arithmetic</td>
<td>2</td>
<td>5</td>
<td>13</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>Problem solving</td>
<td>10</td>
<td>14</td>
<td>19</td>
<td>6</td>
<td>49</td>
</tr>
<tr>
<td>Measurement (general)</td>
<td>18</td>
<td>10</td>
<td>34</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Measurement: body math</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Area/perimeter</td>
<td>5</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Fractions</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Geometry</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Patterns/tessellation</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Numbers/counting</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Graphs</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Estimation</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
As this table indicates, one of the most prevalent responses in all four groups was that children learned about problem solving. Among children’s more specific responses, however, children in the All Materials, DVD + Web, and DVD Only groups most often discussed measurement (including several specific mentions of body math), whereas the Web Only group most often mentioned arithmetic.

Examples of the children’s responses included the following:

“[The television episode about body math] showed me how to guess people’s height and all of that. I just, previously, I didn’t know anything about that. I was just like, “What?” I was like, “Oh! I never knew that.” So it really got me thinking and it was really fun trying to see in the next one seeing how tall Shaq was [in the posttest task]. I was close. I was doing the math-y way. I love math.”

-- Girl, All Materials

“I learned that just ‘cause, like, there’s a perimeter or something, even if it’s the same length, it could be a little different. Like [if] the shorter the width gets… the longer the height gets, then they’re the same. It could be the same but a different shape.”

-- Boy, All Materials

“Like Railroad Repair [game about adding decimals], it helped me get the pieces I need to put in. And Cyber Olympics [game about organizing and using data], that, you get to pick cards, you get to choose wisely. And Bike Route [taxi geometry game], you have to go on these squares and you can only move certain times.”

-- Boy, Web Only

“It teaches me how to do math, like fractions, division, multiplication, addition, subtraction.”

-- Girl, Web Only

Consistent with the children’s perceptions of learning, all of the teachers who were interviewed felt that children had learned from Cyberchase. Examples of teacher comments included:

“Yes, they definitely benefited from using Cyberchase. In particular, they learned to examine problems for ways to solve them. They also worked with data in many different ways and lots of measuring and measurement terms. When looking at specific content, they learned and benefited from practicing with perimeter and area, graphs, estimating and probability.”

“My kids obviously are getting better at problem solving. They don’t give up as easily - even my kids who usually have a hard time with math.”

“At first, some of my parents complained about me asking the kids to watch TV. But, after they saw what [Cyberchase] was about, they didn’t mind.”

“I’m sure my kids are going to do better on ISTEP [standardized tests]. You can just see
it. And, they're much better at explaining what they do. Before, they sometimes could do it, but they couldn't explain...We worked at lot on that - explaining what you're doing to others.”

“I think kids remember things longer when they associate things with stories. They sometimes say, ‘This is like when [the Cyberchase characters did something].”

“There is a child in my room that I know learned from the Web site. She is a below-grade level student, but she really stuck with one game where she had to measure and weigh. It was good for her.”

_perceptions of Cyberchase:_ Perhaps because of the perceived learning discussed above, virtually all of the teachers were quite positive about the educational value and usefulness of _Cyberchase_, and about its appeal for their students. Examples of teacher comments included:

“The characters in the video definitely kept students engaged. As a teacher I believe the hardest part is keeping students interested in the topic.”

“Several of the episodes and games were great and matched the grade level content standards that I am required to cover. They allowed students to experience the same content in new and interesting ways.”

“I like it when my kids like things that are good for them. Not like spinach. My kids attitudes are great. And Cyberchase helped.”

“I’ve learned some new things too. That never hurts. ... I’m now spending more time on richer problems.”

Appeal was strong among children, too. When to rate the appeal of _Cyberchase_ (whichever combination of materials they had used) on a five-point scale of “Great-Good-OK-Not So Good-Terrible,” 87% of children rated _Cyberchase_ as either “good” or “great.” No one rated it below “OK.”

Interestingly, although the educational effects of _Cyberchase_ appeared to be driven more by the television series than by the online games (in that the Web Only group often showed smaller effects than the other _Cyberchase_ groups) – and although all of the groups rated the appeal of _Cyberchase_ positively – appeal was stronger among groups that used the Web site either exclusively or alongside other materials ($F_{2,151} = 3.78, p < .05$).
CONCLUSIONS AND IMPLICATIONS

Together, these data indicate that children’s naturalistic use of multiple media often spans multiple media platforms, and that there are indeed benefits to learning from multiple media over learning from a single medium. Moreover, the data also suggest possible ways in which these benefits might arise.

Use of Multiple Media

Obviously, the benefits of cross-platform learning can arise only if children choose to use multiple media platforms in the first place. Fortunately, the results of the present study suggest that they do. Data from the naturalistic phase clearly indicate that children’s use of Cyberchase was consistent over time and spanned multiple media. Those children who chose to use Cyberchase typically did not engage in one-time use. Instead, they became “Cyberchase fans” whose interest in Cyberchase sustained itself over a period of several months and carried over to both television and the Web.

Certainly, we must be careful in attempting to generalize from Cyberchase to children’s use of other media-based STEM projects. Every project is different and may be used differently, either by design or because of the interests of the children who use them. However, there are good reasons to believe that the patterns of use observed for Cyberchase may be typical of children’s media use as a whole. First, children’s reports regarding their use of SpongeBob Squarepants during the naturalistic phase followed similar patterns. Like Cyberchase, use of SpongeBob Squarepants was consistent across the naturalistic phase, and significant relationships were found between use of the SpongeBob Squarepants television series and Web site. Second, recent research on children’s Web use (unrelated to Cyberchase) also supports the relationship between use of television and the Web. Data on Web usage in 2009 and 2010 found that approximately one-half of the 10 most popular Web sites for children were associated with television programs and characters such as those found on Nickelodeon, Cartoon Network, or PBS (e.g., Kido’z, 2009; Nielsen Online, 2010).

In the present study, as in past research, use of Cyberchase was not driven by either gender, ethnicity, mathematics ability, or prior interest in mathematics as a favorite subject. Rather, past research found that use was motivated by Cyberchase’s entertainment value – its characters, stories, etc. (Fisch, 2005). Since children in the present study rated the appeal of Cyberchase highly, that appears to have been the case here as well. Thus, it appears that appealing STEM media have the potential to attract a diverse audience (including children who do not have a prior affinity for the relevant educational content), and to encourage them to continue their engagement over time and across media.
Benefits for Learning

Past research has shown that children’s knowledge of mathematics and problem-solving skills can be enhanced through use of educational television and computer games (e.g., Clements, 2002; Fisch, 2004), and, more specifically, by the Cyberchase television series (Fisch, 2003; Rockman Et Al., 2002). The present data replicate this finding for the television series and extend it to other Cyberchase media as well. While playing Cyberchase games online, children engaged in increasingly sophisticated cycles of problem solving that resembled the progression that past research has documented for classroom learning (e.g., Lesh, 2000). Subsequently, users of Cyberchase media demonstrated significantly greater gains in problems-solving performance than non-users. Interestingly, these gains were not manifest in children’s simply doing a greater number of things while working on the tasks, but rather in their using a greater variety of strategies and heuristics, and in using those strategies and heuristics more effectively. These sorts of quantitative results fit well with our qualitative observations of children demonstrating top-down planning and persistence in the posttest.

As noted earlier, many of the pretest-posttest effects on problem solving appeared to be driven more by the Cyberchase television series than by the Web site. Perhaps this is to be expected, since television is the central component of the Cyberchase project. Not only did the children in the present study spend more time with the television series than the Web site (because our experimental treatment was designed to simulate real-world use, in which the television series is used more often than the Web site), but the Cyberchase television series carries far more explanation of embedded math concepts and problem solving than the online games do. The story-based format of the Cyberchase television series also may have played a role, by presenting models of successful problem solving in the context of compelling stories. Indeed, numerous researchers have pointed to the power of narrative in conveying and representing information (e.g., László, 2008; Schank & Abelson, 1995). As one of our participating teachers put it, “I think kids remember things longer when they associate things with stories. They sometimes say, ‘This is like when [the Cyberchase characters did something].’”

Because all of the instructional materials in this study were taken from Cyberchase, the present data should not be taken as evidence that television necessarily has greater educational potential than interactive games. It is quite possible that another project, designed with online games as its centerpiece, might find stronger effects for its games than for its video component. The present study was not intended to place different media on equal footing to discover which one is “best,” but rather, to explore how different media might interact to yield cumulative effects, as we shall now discuss.

Cross-Platform Learning

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. Our significant effects on problem solving 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-platform learning can hold benefits for transfer of learning.

The benefits of cross-platform learning 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 three online games, 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 cross-platform learning 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, 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 in the educational research literature on transfer of learning (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.

**Benefits for Attitude**

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.
Implications for the Design of ISE 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. (Interestingly, another recent study also found that the strongest effects were not always found among the experimental group that used the greatest amount of media [Fisch et al., submitted for publication].) 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, the 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.

In these ways, we can build on the lessons learned from past and current research, both to stimulate future research and – even more importantly – to build projects that will take even better advantage of the power of educational media to help children learn.
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