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# Examining Factors That Influence the Effectiveness of Learning Objects in Mathematics Classrooms

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**Abstract:** Learning objects are interactive online tools that support the acquisition of specific concepts. Limited research has been conducted on factors that affect the use of learning objects in K–12 mathematics classrooms. The current study examines the influence of student characteristics (gender, age, computer comfort level, subject comfort level, and mathematics grade), instructional design (structured vs. open ended), and teaching strategy (teacher led vs. student based) on student attitudes toward the use of learning objects and learning performance. Data in the form of surveys and pre- and posttests were collected from 286 middle and secondary school students. Higher computer and subject area comfort ratings were significantly correlated with more positive student attitudes about learning objects. Older students in higher grades learned more than younger students in lower grades after using learning objects. Learning performance was significantly higher for students who used structured (vs. open-ended) learning objects and participated in teacher-led (vs. student-based) lessons. It is speculated that younger students might need more scaffolding when using mathematics-based learning objects.

**Résumé:** Les objets d'apprentissages sont des outils en ligne qui facilitent l'acquisition de certains concepts spécifiques. Il y a peu de recherches sur les facteurs qui affectent l'utilisation des objets d'apprentissage dans les cours de mathématiques en cinquième année de secondaire. La présente étude se penche sur l'influence des caractéristiques individuelles des étudiants (sexe, âge, habiletés informatiques, connaissance de la matière et notes obtenues en mathématiques), le type de matériel pédagogique (structuré ou ouvert) et les stratégies d'enseignement (enseignement dirigé par les enseignant ou basé sur les apprenants) sur les attitudes à l'égard de l'utilisation des objets d'apprentissage et la performance. Les données, sous forme d'enquêtes et de pré-tests et post-tests, ont été recueillies à partir des réponses de 286 étudiants de niveau élémentaire (deuxième cycle) et secondaire. Il y a une corrélation significative entre d'une part les habiletés informatiques ainsi que le niveau de connaissance de la matière, et d'autre part l'attitude positive devant les objets d'apprentissage. Les étudiants plus âgés et ceux des niveaux supérieurs ont mieux appris grâce à l'utilisation des objets d'apprentissage que les élèves les plus jeunes et ceux des niveaux inférieurs. La performance d'apprentissage est significativement plus élevée chez les étudiants qui ont utilisé des objets d'apprentissage structurés et chez ceux qui ont participé à des cours dirigés par les enseignants. Nous avançons l'hypothèse que les élèves les plus jeunes ont besoin d'un soutien plus marqué lorsqu'ils se servent des objets d'apprentissage en mathématiques.

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## OVERVIEW

Originally designed for higher education, learning objects are now being used more often in middle and secondary school classrooms (e.g., Clarke & Bowe, 2006a, 2006b; Kay & Knaack, 2007b, 2008c, 2008d; Liu & Bera, 2005; Lopez-Morteo & Lopez, 2007; Nurmi & Jaakkola, 2006). Though some research has been done on the use of learning objects in mathematics (Kay & Knaack, 2008d), a comprehensive examination of factors that might influence the effectiveness of learning objects including student characteristics, design of learning objects, and teaching strategy has yet to be conducted. The purpose of the current study was to examine key variables that might contribute to the successful implementation of learning objects in middle and secondary school mathematics classrooms.

### Definition of Learning Objects

*Learning objects* are operationally defined in this study as interactive Web-based tools that support the learning of specific concepts by enhancing, amplifying, and/or guiding the cognitive processes of learners. This definition is an aggregate of previous attempts to define learning objects (Agostinho, Bennett, Lockyer, & Harper, 2004; Butson, 2003; McGreal, 2004; Parrish, 2004; Wiley et al., 2004). Some examples used by teachers in this study include adding integers with virtual colored tiles, visual presentation of how coordinates work on a two-dimensional graph followed by a set of test questions, animations of how three-dimensional objects transform to two-dimensional nets in order to examine surface area, and manipulation of parameters in a parabolic equations. Links to all learning objects used in this study are provided in Appendix A (Kay, 2011a).

### Benefits of Using Learning Objects

Three key features of learning objects that benefit students are visual supports, motivation through increased focus, and control over learning. Visual supports help make complex ideas more easily understood by reducing working memory and cognitive load (Kay & Knaack, 2008c; Sedig & Liang, 2006). Visualization is particularly important in mathematics where it is challenging for many students to understand abstract concepts (Grouws, 2004; Kilpatrick, Martin, & Schifter, 2003; Sowder & Schappelle, 2002). Many learning objects also provide clear learning goals and immediate feedback, characteristics that frequently lead to increased focus and motivation (Barkley, 2010; Wlodkowski, 2008). Focus and specific feedback is especially helpful in multistep mathematics problems. Finally, learning objects permit students to control the pace of learning, thereby providing easier digestion of new concepts (Bransford, Brown, & Cocking, 2000; Kay & Knaack, 2008c, 2008d; Willingham, 2009). The rate at which students understand mathematics concepts varies considerably, so being able to control the pace of learning is important (Grouws, 2004; Sowder & Schappelle, 2002). In summary, a carefully designed learning object can provide visual scaffolding, decreased cognitive load, increased motivation and focus, and control over the learning process, thereby resulting in more productive learning experiences.

## Overview—Learning Objects and Mathematics

A comprehensive review of articles on the use of learning objects in the past 10 years revealed nine studies examining the use of mathematics-based learning objects in K–12 schools (Bower, 2005; Clarke & Bowe, 2006a, 2006b; Kay & Knaack, 2007c, 2008d; Kong & Kwok, 2005; Lopez-Morteo & Lopez, 2007; Nurmi & Jaakkola, 2006a; Reimer & Moyer, 2005).

Seven studies indicated that student attitudes toward mathematics-based learning objects was largely positive (Clarke & Bowe, 2006a, 2006b; Kay & Knaack, 2007c, 2008d; Lopez-Morteo & Lopez, 2007; Nurmi & Jaakkola, 2006; Reimer & Moyer, 2005). Features that students liked about learning objects included ease of use, controlling the pace of learning, timely feedback, using a wide range of multimedia tools, and support for learning (Clarke & Bowe, 2006a, 2006b; Kay & Knaack, 2007c, 2008d; Lopez-Morteo & Lopez, 2007; Nurmi & Jaakkola, 2006; Reimer & Moyer, 2005). Lim, Lee, and Richards (2006) and Nurmi and Jaakkola (2006) added that the acceptance of learning objects was partially dependent on the type of learning object used. Students favored interactive, constructive learning objects over an "electronic" textbook prototype. Kay and Knack (2007a) offered quantitative evidence that students were moderately positive about using mathematics-based learning objects.

Four of the nine studies reviewed reported that elementary and middle school students who used learning objects showed significant improvement on various learning performance measures (Bower, 2005; Kong & Kwok, 2005; Nurmi & Jaakkola, 2006; Reimer & Moyer, 2005). Nurmi and Jaakkola (2006) noted that learning performance gains were dependent on the type of learning object and how it was used. Students working with drill and practice learning objects were more focused on competing with their peers than on learning. Students involved in a mixed learning object/lab-based lesson performed significantly better than in other learning scenarios.

## Student Characteristics and Learning Objects

Though research on student characteristics and the use of learning objects is relatively limited, several recent studies in the area of mathematics and science (e.g., Kay, 2009a, 2011c; Kay & Knaack, 2007b, 2008a, 2008c) suggested that there are at least five potential attributes that could influence the effectiveness of learning objects, including gender, age, computer comfort level, subject comfort level, and ability.

Three studies (Kay & Knaack, 2007b, 2008a, 2008c) reported no significant differences between male and female secondary school students' attitudes and learning performance when learning objects were used. Kay and Knaack (2007b, 2008c) observed that older students (Grade 12) were more positive about learning objects and performed better than younger students (Grades 9 and 10). De Salas and Ellis (2006) added that second- and third-year university students were far more open to using learning objects than first-year students. Several studies noted that computer comfort was significantly and positively correlated with student attitudes toward the learning, design, and engagement value of learning objects (Kay & Knaack, 2005, 2007b, 2008a, 2008c; Kay, 2009a). Lim et al. (2006) added, in a case study, that students who were not comfortable with computers used learning objects less. Finally, Kay and Knaack (2008c) recommended that subject-area comfort level and aptitude be examined when looking at individual differences in the use of learning objects.

## Learning Objects and Instructional Architecture

As least two distinct categories of learning objects exist: structured and open ended. Structured learning objects typically deliver short sequences of information and then test students' knowledge or allow limited practice with the concepts being learned. Clark (2008) referred to this type of learning object as receptive or directive. Open-ended learning objects use a problem-based format where students explore and test what-if scenarios to discover relationships and/or improve understanding of specific concepts.

Substantial debate exists about the optimum level of instructional guidance required for successful learning (Kirschner, Sweller, & Clark, 2006). Some researchers maintain that students need to be provided with sufficient structure to learn effectively (e.g., Cronbach & Snow, 1977; Mayer, 2004; Sweller, 1998), particularly when their knowledge and understanding is limited within a given subject area (Kirschner et al., 2006). Kirschner et al. (2006) added that students can become overwhelmed with learning new concepts and the cognitive demands of an open-ended format.

Other researchers suggested that learning is best supported when students are given the essential tools in an open-ended environment and required to construct understanding themselves (e.g., Bruner, 1986; Steffe & Gale, 1995; Vannatta & Beyerbach, 2000; Vygotsky, 1978). This minimal level of instructional guidance is referred to by a variety of names, including *discovery*, *problem-based*, and *inquiry learning* (Kirschner et al., 2006). The more open-ended, constructivist approach has grown in popularity over the past 10 years (Kirschner et al., 2006) and is prominent in the National Council of Teachers of Mathematics' *Principles and Standards for School Mathematics* (2001).

Bransford et al. (2000), in their seminal work, *How People Learn*, proposed that both structured and open-ended approaches are necessary for students to develop competence in an area of learning. At times, structured delivery of information can work to help build a foundation of factual knowledge organized within a conceptual framework. As students become more knowledgeable, an open-ended approach is more viable because students can redirect their cognitive attention from understanding basic concepts to controlling, monitoring, and assessing their own progress (Bransford et al., 2000). To date, the influence of the underlying instructional architecture of learning objects has not been examined.

## Teaching Strategies

An increasing number of theorists argue that the effectiveness of any learning object is largely dependent on the pedagogical choices of the instructor (e.g., Alonso, Lopez, Manrique, & Vines, 2005; Haughey & Muirhead, 2005; McCormick & Li, 2005). Strategies that have been successfully used with learning objects include coaching or facilitating (e.g., Liu & Bera, 2005), establishing context (e.g., Schoner, Buzza, Harrigan, & Strampel, 2005), instructing students to evaluate their own actions (e.g., van Merrienboer & Ayres, 2005), and providing some sort of instructional guide or scaffolding (e.g., Concannon, Flynn, & Campbell, 2005; Kay, Knaack, & Muirhead, 2009; Lim et al., 2006; Mason, Pegler, &Weller, 2005).

One important issue is the amount of support offered by an instructor. Minimal teacher guidance appears to work in higher education (e.g., Kong & Kwok, 2005; Reimer & Moyer, 2005) but not in middle and high school classrooms (Kay & Knaack, 2007a; Nurmi & Jaakkola, 2006).

The cognitive demands of using a learning object independently may be too high for younger students; consequently, a teacher-led approach may work better than a student-based approach.

## Purpose

The purpose of this study was to examine the influence of student characteristics, instructional architecture, and teaching strategy on the effectiveness of learning objects in the secondary school mathematics classrooms.

# METHOD

## Overview

The following protocol was followed to maximize the quality of data collected:

1. A relatively large group of students was sampled.
2. Reliable, valid, and research-based survey tools were employed to collect data on student attitudes toward learning objects (Kay & Knaack, 2009b).
3. Mathematics-based learning objects were preselected for teachers based on Kay and Knaack's (2008b) multicomponent approach for evaluating learning objects.
4. Predesigned lesson plans were created by trained teachers and derived from previous research looking at effective strategies for using learning objects.
5. An enhanced measure of student performance was developed for each learning object based on the revised Bloom's taxonomy (Anderson & Krathwohl, 2001).

## Sample

### *Students*

The student sample consisted of 286 middle and secondary school students (132 males, 154 females) who were 11–17 years of age ($M = 12.8$, $SD = 0.91$). Most students reported average grades of 60–69% ($n = 43$, 15%), 70–79% ($n = 113$, 40%), or 80–89% ($n = 83$; 29%). Just over 60% ($n = 182$) agreed that they were good at the subject in which the learning object was used. Only 40% ($n = 119$) agreed that they liked the subject taught with the learning object. Three quarters of the students ($n = 217$) agreed or thought that they were good at working with computers. The sample population was collected from 15 different middle and secondary school classrooms located within two suburban regions with over 500,000 people each.

### *Teachers*

Twelve middle school and three secondary school teachers participated in this study (5 males, 10 females). Specific grades taught were 7th ($n = 6$), 8h ($n = 6$), 9th ($n = 2$) and 10th ($n = 1$). Teaching experience ranged from 0.5–23 years with a mean of 7.6 ($SD = 7.0$). Thirteen out of 15 teachers (87%) agreed that they were comfortable with using computers at school. Frequency of typical classroom computer use varied widely, with two teachers never using computers, one teacher using computers once a year, four teachers using computers each term, five teachers using computers monthly, two teachers using computers weekly, and one teacher using computers on a daily basis.

### *Learning Objects and Lesson Plans*

Four teachers, not involved in the study, were recruited to select high-quality learning objects and create lesson plans. Each of these teachers participated in a two-day workshop looking at how to (a) select learning objects for the classroom and (b) develop effective lesson plans. The criteria for choosing learning objects was based on Kay and Knaack's (2008b) multicomponent model for evaluating learning objects. The lesson plan design was derived from the results of Kay et al.'s (2009) study on effective strategies for using learning objects. Key components of a standard lesson plan included (a) a guiding set of questions; (b) a structured, well-organized plan for using the learning objects; and (c) time to consolidate concepts learned. A typical lesson was approximately 70 minutes in duration and included an introduction (10 minutes), guiding questions and activities involving the use of an learning object (50 minutes), and consolidation (10 minutes).

A database of 44 lesson plans and learning objects was created over a period of 2 months. Nine unique learning objects were selected by teachers from the learning object database. See Appendix A (Kay, 2011a) for a links to all learning objects, lesson plans, and pre- and posttests used by mathematics teachers in this study.

## Procedure

Mathematics teachers from two boards of education were informed of the research study by an educational coordinator. Teachers who volunteered for the study participated in full-day training workshop on using learning objects and implementing the predesigned lesson plans. If teachers still wanted to be part of the study after the workshop, they were asked to use at least one learning object in their mathematics classroom within the following 3 months. E-mail support was available for the duration of the study. All students in a given teacher's class participated in the learning object lesson chosen by the teacher; however, survey and pre- and posttest data were only collected from those students with signed parental permission forms.

## Explanatory Variables

Three explanatory variables were examined in this study: student characteristics, learning object instructional architecture, and teaching strategy. The five student characteristics were gender, age, computer comfort level, subject comfort level, and average grade in subject area associated with the learning object used. Computer comfort was assessed using a scale developed by Kay and Knaack (2005), which showed good construct validity and reliability. The internal reliability for the computer comfort scale used in the current study was 0.82. Subject comfort level was measured using two questions asking students about their ability and attitude regarding the learning object subject area. The internal reliability for subject comfort scale used in this study was 0.77. Finally, students were asked to estimate their average grade in the subject area where the learning object was used.

To assess instructional architecture, each learning object was categorized according to its main pedagogical design: structured ($n = 57$) or open ended ($n = 227$). A structured learning object presented information and then tested students for understanding. Information was presented in a relatively passive manner. An open-ended learning object permitted students to change various parameters, explore, and test what-if scenarios (Clark, 2008). See Appendix A (Kay, 2011a) for examples of each learning object architecture type.

Finally, teaching strategy was determined by the lesson plan format used: teacher led ($n = 59$) vs. student based ($n = 224$). In a teacher-led format, the instructor displayed the learning object at the front of the class using an LCD projector and guided the class with a deliberate set of questions and activities. In a student-based lesson, students worked independently on a guiding set of questions in a computer lab. See Appendix A (Kay, 2011a) for all teacher-led and student-based lesson plans used in the study.

## Response Variables

### *Student Attitudes Toward Learning Objects*

When a learning object lesson was finished, students with signed permission forms filled in the *Learning Object Evaluation Scale for Students* (Kay & Knaack, 2007, 2009b) to assess their perceptions of how much they had learned (learning construct), the design of the learning object (design construct), and how engaged they were while using the learning object (engagement construct). These constructs were based on a comprehensive review of the literature on evaluating learning objects (Kay & Knaack, 2007, 2009a). The scale showed good reliability, face validity, construct validity, convergent validity, and predictive validity (Kay & Knaack, 2009b). Internal reliability scale estimates in the current study were 0.94 (perceived learning), 0.82 (design of learning object), and 0.92 (engagement). See Appendix B (Kay, 2011b) for a copy of the scale used.

### *Student Performance*

Students completed pre- and posttests based on the content of the specific learning object they used in class. These tests were included with all predesigned lesson plans to match the learning goals of the learning object (see Appendix A, Kay, 2011a). The percentage difference between pre- and posttest scores was used to assess changes in student performance on four possible knowledge categories from the revised Bloom's taxonomy (Anderson & Krathwhol, 2001) and included remembering, understanding, application, and analysis. The number of knowledge categories assessed in any one class varied according the learning goals of each learning object used.

## Key Research Questions

The following five research questions were examined:

1. What are student attitudes (learning, design, engagement) toward mathematics-based learning objects?
2. How do students perform as a result of using mathematics-based learning objects?
3. How are student characteristics (gender, age, teaching experience, computer comfort level, and subject area comfort level) related to student attitudes about mathematics-based learning objects and learning performance?
4. How is learning object instructional architecture (structured vs. open ended) related to student attitudes about mathematics-based learning objects and learning performance?
5. How is teaching strategy (teacher-led vs. student-based lessons) related to student attitudes about mathematics-based learning objects and learning performance?

## RESULTS

### Lesson Plan Evaluation

The lesson plans for the learning objects were designed by other teachers, so it is prudent to evaluate the extent to which teachers accepted and followed these lesson plans. It is possible that the influence of learning objects is partially dependent on teacher acceptance or rejection of the predesigned lesson plans. Fourteen out of 15 teachers agreed or strongly agreed that the lesson plans were easy to follow. Two thirds of the teachers believed that the lesson plans matched their teaching style. Nearly three quarters of the teachers felt that the handouts were clear and over 85% believed that they were useful. Ninety-five percent of teachers felt that the lesson plans were well designed and 80% believed that there was no need to make changes.

### Student Attitudes Toward Learning Objects

#### *Survey Data—Learning Construct*

Students, on average, somewhat agreed that learning objects helped them learn (Items 8a–8e, Appendix B, Kay, 2011b; $M = 24.3$, $SD = 7.1$), with a mean item rating of 4.9 out of 7. The broad range of scores (5–35) indicates that there was considerable variability among students with respect to their attitudes toward the learning impact of learning objects. Overall, a majority of students agreed that learning objects helped their learning (49% agreed vs. 11% disagreed; Table 1).

#### *Survey Data—Design Construct*

Students rated the design of learning objects (Items 7a–7d, Appendix B, Kay, 2011b) slightly higher than the learning value ($M = 21.1$, $SD = 4.5$) with a mean item rating of 5.3 out of 7. The range of student attitudes toward learning object design (4–28) demonstrated considerable variance. Overall, most students agreed that the learning objects were well designed (66% agreed vs. 4% disagreed; Table 1).

TABLE 1
Student Rating of Learning, Design, and Engagement for Mathematics-Based Learning Objects

| Scale | No. items | Disagree[a] (%) | Agree[b] (%) | Mean (*SD*) |
|---|---|---|---|---|
| Learn | 5 | 11.3 | 49.1 | 24.3 (7.1) |
| Design | 4 | 4.2 | 65.8 | 21.1 (4.5) |
| Engagement | 4 | 18.6 | 46.7 | 18.8 (6.2) |

[a]Percentage of students who disagreed that learning objects helped learning (including somewhat disagree, disagree, strongly disagree). [b]Percentage of students who disagreed that learning objects helped learning (including somewhat agree, agree, strongly agree).

### *Survey Data—Engagement Construct*

Student ratings of learning object engagement (Items 9a–9d, Appendix B, Kay, 2011b) were the lowest of all three attitude constructs ($M = 18.8$, $SD = 6.2$) with a mean item rating of 4.7 out of 7. This means that students, on average, were neutral about or slightly agreed that the learning object they used was engaging. High variability was observed among student engagement ratings (4–28). Overall, almost half of the students felt that the learning objects were engaging (47% agreed vs. 19% disagreed; Table 1).

## Learning Performance

Five paired *t*-tests were performed to assess differences between pre- and posttest scores: four knowledge categories and total test score. Though a multivariate analysis of variance (MANOVA) is a common statistical procedure used with multiple dependent variables, not all of Bloom's knowledge categories were asked for each learning object. In other words, no learning object targeted all four knowledge categories. The MANOVA analysis eliminated considerable data; therefore, multiple *t*-tests were used to incorporate the maximum amount of information possible. The alpha rate was not adjusted to reflect the fact that multiple tests were conducted because the current study is considered formative in nature. All question categories showed significant gains (see Table 2). Increases in scores ranging from 14 to 29% resulted in moderate to large effect sizes based on Cohen's *d* (Cohen, 1988, 1992). Note that the results for the understanding and

TABLE 2
Change in Learning Performance for Students Using Mathematics-Based Learning Objects

| Question type | Pretest mean (%) | Posttest mean (%) | % Change | *n* | *t* | Effect size |
|---|---|---|---|---|---|---|
| Remembering | 60.8 (43.5) | 77.5 (38.5) | 16.6 | 77 | 4.0** | 0.41 |
| Understanding | 7.1 (18.9) | 35.7 (37.8) | 28.6 | 7 | 2.8* | 0.96 |
| Application | 54.9 (31.9) | 69.7 (29.8) | 14.8 | 221 | 6.8** | 0.48 |
| Analysis | 52.1 (43.7) | 78.2 (39.7) | 26.1 | 23 | 2.7* | 0.63 |
| Total score | 55.1 (30.7) | 70.6 (28.3) | 15.4 | 228 | 7.5** | 0.52 |

*$p < .05$. **$p < .001$.

TABLE 3
Correlations Among Student Characteristics, Attitudes Toward Learning Objects, and Learning Performance ($n = 284$)

| Scale | Gender | Grade level | Computer comfort | Subject comfort | Subject mark |
|---|---|---|---|---|---|
| Student attitudes | | | | | |
| Learning | 0.10 | −0.07 | 0.29* | 0.28* | −0.09 |
| Design | 0.03 | 0.03 | 0.27* | 0.41* | 0.11 |
| Engagement | 0.08 | −0.04 | 0.28* | 0.47* | 0.04 |
| Learning performance | 0.00 | 0.26* | 0.01 | 0.03 | 0.08 |

*$p < .001$.

analysis knowledge categories should be treated with caution because of small samples sizes and marginal probability levels.

## Student Characteristics and Learning Objects

### *Attitudes Toward Learning Objects*

Subject and computer comfort level were significantly correlated with higher ratings of learning ($p < .001$), design ($p < .001$), and engagement ($p < .001$). When students were more comfortable with the subject area taught and with using computers, they had more positive attitudes toward learning objects. Student gender, age, and average grade in mathematics were not significantly correlated with student attitudes toward learning objects (Table 3).

### *Learning Performance*

Student age was significantly correlated with learning performance ($p < .001$). Older students in higher grades performed better than younger students in lower grades when learning objects were used. Student gender, subject area comfort level, average grade, and computer comfort level were not significantly correlated with learning performance (Table 3).

## Learning Object Instructional Architecture

Students who used structured learning objects rated learning value ($p < .05$) significantly higher than students who used open-ended learning objects. The effect size according to Cohen (1988, 1992) was considered moderate. No significant differences were observed between structured and open-ended learning objects with respect to student ratings of design or engagement. Total learning performance was significantly higher when structured as opposed to open-ended learning objects were used ($p < .001$). The effect size for this difference was considered large according to Cohen (1988, 1992; see Table 4).

TABLE 4
Student Attitudes and Total Learning Performance as a Function of Learning Object Instructional Architecture

| Question type | Structured ($n = 57$) Mean (*SD*) | Open-ended ($n = 226$) Mean (*SD*) | *df* | *t* | Effect size |
|---|---|---|---|---|---|
| Student attitudes | | | | | |
| Learning | 22.6 (7.4) | 24.9 (6.9) | 281 | 2.3* | 0.32 |
| Design | 21.5 (4.0) | 20.9 (4.6) | 282 | 1.0 | |
| Engagement | 18.4 (6.2) | 19.0 (6.1) | 283 | 0.6 | |
| Total learning performance | 30.1 (34.4) | 10.6 (28.2) | 226 | 3.9** | 0.62 |

*$p < .05$. **$p < .001$.

## Teaching Strategy and Learning Objects

Students rated learning object design significantly higher for teacher-led as opposed to student-based lessons ($p < .005$). The effect size for this difference is considered moderate according to Cohen (1988, 1992). No significant differences were observed with respect to student ratings of learning object learning and engagement constructs as a function of teaching strategy. Total student performance was significantly higher for teacher-led versus student-based learning object lessons ($p < .005$). The effect size for this difference is considered moderate according to Cohen (1988, 1992; see Table 5).

# DISCUSSION

The purpose of this study was to examine the influence of student characteristics, instructional architecture, and teaching strategy on student attitudes toward learning objects and learning performance in middle and secondary school mathematics classrooms.

TABLE 5
Student Attitudes Toward Learning Objects and Total Learning Performance as a Function of Teaching Strategy.

| Question type | Teacher led ($n = 59$) | Student based ($n = 224$) | *df* | *t* | Effect size |
|---|---|---|---|---|---|
| Student attitudes | | | | | |
| Learning | 24.9 (6.4) | 24.1 (7.3) | 281 | 0.8 | |
| Design | 22.5 (2.9) | 20.7 (4.7) | 282 | 2.9* | 0.46 |
| Engagement | 19.3 (5.7) | 18.7 (6.3) | 283 | 0.7 | |
| Total learning performance | 28.8 (32.1) | 12.4 (30.0) | 226 | 3.1* | 0.53 |

*$p < .005$.

## Student Attitudes and Learning Performance for Mathematics-Based Learning Objects

Middle and secondary school students, on average, agreed that mathematics-based learning objects were well designed, engaging, and helpful when learning. This result was also reported in previous studies (Kay & Knaack, 2007a, 2009a; Lowe et al., 2010). The wide range of ratings for learning, design, and engagement constructs suggests that some students do not benefit from using learning objects. For example, a small group (11–19%) believed that learning objects did not help them learn or were not engaging. More research is needed to determine the source of resistance toward using learning objects.

Significant learning performance gains were seen in all four of Bloom's knowledge categories (Anderson & Krathwhol, 2001). Increases from 15 to 29% and effect sizes in the moderate to large range (Cohen 1988, 1992) indicate that the change was sizeable, not just statistically significant. The largest increases were observed in questions focusing on understanding (29%) and analysis; however, the sample size was small, so more research is needed to confirm whether these gains are consistent. The smallest gains were observed for remembering (17%) and application (15%) knowledge areas. These two areas were the main learning targets in this study, perhaps a reflection that learning objects for this age group tend to focus on basic as opposed to higher level concepts. Because this is a first study examining the impact of learning objects on different knowledge areas, the results should be treated with caution.

## Student Characteristics

### *Student Attitudes Toward Learning Objects*

Only two variables were significantly correlated with student attitudes toward learning objects: computer comfort level and subject comfort level. Students who were more comfortable with computers and mathematics had significantly more positive attitudes than their less confident peers. This result was partially confirmed by previous research on computer comfort level (Kay & Knaack, 2005, 2007b, 2008c; Lim et al., 2006); however, the result for the impact of subject area confidence was new.

Gender, grade level, and self-reported ability in mathematics were not significantly correlated with student attitudes toward learning objects. The results for gender were consistent with previous studies on gender differences and learning objects (e.g., Kay & Knaack, 2007b, 2008c). A pattern is beginning to emerge that learning objects are relatively gender neutral for mathematics-based learning objects. On the other hand, the absence of a grade-level effect on student attitudes toward learning objects does not match the results of previous research (e.g., De Salas & Ellis, 2006; Kay & Knaack, 2007b, 2008c). One possible explanation for this difference may be that the students in the current study were younger. These students born in the net generation (Tapscott, 2008) have grown up on a steady diet of computer technology, perhaps negating the impact of grade level on attitudes toward using learning objects (Montgomery, 2009; Palfrey & Gasser, 2008; Tapscott, 2008). The absence of any relationship between self-rated ability in mathematics and attitudes toward learning objects has not been examined prior to this study, so the results should be considered preliminary.

### *Learning Performance*

The only student characteristic significantly correlated with learning performance was age. Older students in higher grades performed significantly better than younger students in lower grades. This result was partially supported by previous research reporting a modest, positive age effect on general learning performance after using learning objects (Kay & Knaack, 2007b, 2008c). One explanation for the impact of age on learning performance might involve the range of skills required to use a learning object including reading instructions, writing down results, and interpreting what-if scenarios. Older students may be able to cope with these cognitive demands, whereas younger students may need more scaffolding.

Gender, computer comfort level, subject comfort level, and self-reported math ability were not significantly correlated with learning performance. The absence of a gender effect is consistent with past research (e.g., Kay & Knaack, 2007b, 2008c). This result provides further evidence that learning objects are educational tools that serve male and female students equally well. The conclusion is noteworthy given that small but persistent gender differences in the use of technology have been observed over the past 20 years, usually in favor of males (e.g., American Association of University Women, 2000; Sanders, 2006; Whitley, 1997).

It is interesting that computer and student comfort level had a significant impact on student attitude but not learning. One implication from this finding may be that learning objects work reasonable well regardless of how comfortable a student is with using computers or doing mathematics.

It is somewhat surprising that mathematics grades were not correlated with learning performance. One would expect that students with higher grades would perform better than students with lower grades most of the time. One obvious explanation is that students were not able to accurately assess their current grades. However, the range of grades selected by students was highly variable and there was no reason to assume a systematic bias. It was assumed that students had a general sense of how well they were doing. It is also possible that using learning objects minimized the impact of average grade and helped level the academic playing field. Future research should collect actual student grades in order to determine whether the current results are robust.

## Learning Object and Instructional Architecture

Students were equally positive about the design and engagement value for structured versus open-ended learning objects. However, students using structured learning objects felt that they learned significantly more and outperformed peers who used open-ended learning objects by almost 20%. This result supports Kirschner et al.'s (2006) assertion that younger students may not be able to handle the cognitive demands of self-guided discovery required in an open-ended format, particularly when a firm foundation in mathematical concepts has not been established. However, before making the assumption that structured learning objects are more appropriate for younger students, several alternative explanations need to be considered. For example, it is conceivable that younger students are simply more familiar with structured learning objects and therefore respond to them more positively. Another interpretation might be that structured learning objects are easier to complete in a single class than open-ended learning objects, which may require more time to discover and construct solutions. A third possibility is that structured learning objects may be more effective in addressing remembering and application knowledge areas, the two main Bloom's categories assessed in this study. It is reasonable to speculate that open-ended learning objects might be more effective in targeting understanding and analysis knowledge areas. More research is needed, perhaps in the form of qualitative observations of interviews, in order to understand why middle and secondary school students respond differently to a structured vs. open-ended learning object design. In addition, a larger sample is needed to determine the impact of instructional architecture on specific knowledge areas.

## Teaching Strategy

Student learning performance and, to a lesser extent, student attitudes were significantly higher for teacher-led as opposed to student-based lesson plans. These findings are consistent with those observed by several previous studies (Kay & Knaack, 2007a; Nurmi & Jaakkola, 2006). Middle and secondary school students in Grades 7–10 appear to need more scaffolding and guidance when using learning objects. This result is important given that the traditional approach to using learning objects is to encourage students to work independently on their own computers (e.g., Kong & Kwok, 2005; Reimer & Moyer, 2005).

Again, these results need to be treated with caution for at least two reasons. First, the sample size of students who used teacher-led learning objects was relatively small. Second, the instructional architecture used within each teaching strategy was not strictly balanced (see Appendix A, Kay, 2011a), so it is possible that there was an interaction effect. For example, open-ended learning objects may require more teacher guidance than structured learning objects. Future research using equal numbers of structured and open-ended learning objects within each teaching strategy would help investigate possible interactions between instructional architecture and method of instruction.

## Caveats and Future Research

Several steps were followed to ensure the quality of data collection and analysis in this study, including controlling for the design of learning objects and lesson plans; using a wide range of learning objects; employing reliable, valid data assessment tools; and assessing a wide range of learning performance knowledge areas. Still, several limitations remain and need to be addressed in future studies.

First, the sample size needs to be increased to more thoroughly assess instructional design, teaching strategies, and all four of the revised Bloom's knowledge categories. Second, a more in-depth analysis involving qualitative data is needed to determine whether younger students require more scaffolding when using learning objects and what this support might look like. Third, the results of the current study are based on one-time use of learning objects. It is not clear what the long-term impact of student characteristics, instructional design, and teaching strategy on attitudes and learning performance would be. Finally, a wider range of teaching strategies could be examined to determine the optimal guidance needed when using learning objects in middle and secondary school mathematics classrooms.

## Summary

This study looked at factors that influenced student attitudes toward mathematics-based learning objects and learning performance. Overall, students thought that learning objects were well-designed, engaging tools that helped them learn. Posttest scores increased significantly over pretest scores after using learning objects, an average of 15%. However, individual student characteristics, instructional design, and teaching strategy were intricately linked to the impact of learning objects. A student's computer and subject area comfort level (student characteristics) were significantly correlated with student attitudes toward learning objects but not learning performance. Older students in higher grades performed better with learning objects than younger students in lower grades. Students who used structured learning objects performed significantly better than students who worked with open-ended learning objects; however, this may be a reflection of the type of knowledge areas assessed. Finally, students involved in a teacher-led learning object lesson significantly outperformed students who participated in a student-based lesson. The results suggest that younger students may need more guidance and scaffolding if learning objects are to be successful in middle and secondary school mathematics classrooms.

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