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Evaluating the learning in learning objects

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A comprehensive review of the literature on the evaluation of learning objects revealed a number of problem areas, including emphasizing technology ahead of learning, an absence of reliability and validity estimates, over-reliance on informal descriptive data, a tendency to embrace general impressions of learning objects rather than focusing on specific design features, the use of formative or summative evaluation, but not both, and testing on small, vaguely described sample populations using a limited number of learning objects. This study explored a learning-based approach for evaluating learning objects using a large, diverse, sample of secondary school students. The soundness of this approach was supported by estimates of reliability and validity, using formal statistics where applicable, incorporating both formative and summative evaluations, examining specific learning objects features based on instructional design research, and testing of a range of learning objects. The learning-based evaluation tool produced useful and detailed information for educators, designers and researchers about the impact of learning objects in the classroom.

Keywords: *Evaluate; Assess; Quality; Secondary school; Learning object*

Overview

According to Williams (2000), evaluation is essential for every aspect of designing learning objects, including identifying learners and their needs, conceptualizing a design, developing prototypes, implementing and delivering instruction, and improving the evaluation itself. It is interesting to note, however, that Williams (2000) does not emphasize evaluating the impact of learning objects on 'actual learning'. This omission is representative of the larger body of research on learning objects. In a recent review of 58 articles (see Kay & Knaack, submitted), 11 studies focused on the evaluation of learning objects; however, only two papers examined the impact of learning objects on learning.

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A number of authors note that the 'learning object' revolution will never take place unless instructional use and pedagogy are explored and evaluated (for example, Wiley, 2000; Muzio *et al.*, 2002; Richards, 2002). Duval *et al.* (2004) add that while many groups seem to be grappling with issues that are related to the pedagogy of learning objects, few papers include a detailed analysis of specific learning object features that affect learning. Clearly, there is a need for empirical research that focuses on evaluating the learning-based features of learning objects. The purpose of this study was to explore and test a learning-based approach for evaluating learning objects.

Literature review

Definition of learning objects

It is important to establish a clear definition of a 'learning object' in order to develop an effective metric. Unfortunately, consensus regarding a definition of learning objects has yet to be attained (for example, Muzio *et al.*, 2002; Littlejohn, 2003; Parrish, 2004; Wiley *et al.*, 2004; Bennett & McGee, 2005; Metros, 2005). Part of the problem rests in the values and needs of learning object developers and designers. The majority of researchers have emphasized technological issues such as accessibility, adaptability, the effective use of metadata, reusability and standardization (for example, Muzio *et al.*, 2002; Downes, 2001; Littlejohn, 2003; Siqueira *et al.*, 2004; Koppi *et al.*, 2005). However, a second 'learning focused' pathway to defining learning objects has emerged as a reaction to the overemphasis of technological characteristics (Baruque & Melo, 2004; Bradley & Boyle, 2004; Wiley *et al.*, 2004; Cochrane, 2005).

While both technical and learning-based definitions offer important qualities that can contribute to the success of learning objects, research on the latter, as indicated, is noticeably absent (Kay & Knaack, submitted). Agostinho *et al.* (2004) note that we are at risk of having digital libraries full of easy-to-find learning objects we do not know how to use in the classroom.

In order to address a clear gap in the literature on evaluating learning objects, a pedagogically focused definition of learning objects has been adopted for the current study. Learning objects are defined as 'interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and guiding the cognitive processes of learners'. Therefore, specific learning qualities are valued more highly than the technical qualities in the evaluation model being developed and assessed.

Theoretical approaches to evaluating learning objects

Summative versus formative evaluation. Researchers have followed two distinct paths for evaluating learning objects—summative and formative. The first and most frequently used approach is to provide a summative or final evaluation of a learning object (Kenny *et al.*, 1999; Van Zele *et al.*, 2003; Adams *et al.*, 2004; Bradley & Boyle, 2004; Jaakkola & Nurmi, 2004; Krauss & Ally, 2005; MacDonald *et al.*, 2005). Various summative formats have been used, including general impressions gathered using informal interviews or surveys, measuring frequency of use and assessing learning outcomes. The ultimate goal of this kind of evaluation has been to get an overview of whether participants valued the use of learning objects and whether their learning performance was altered. The second approach involves the use of formative assessment when learning objects are being developed, an approach that is strongly supported by Williams (2000). Cochrane (2005) provides a good example of how this kind of evaluation model works where feedback is solicited from small groups at regular intervals during the development process. Overall, the formative approach to evaluation is not well documented in the learning object literature.

Convergent participation. Nesbit *et al.* (2002) outline a convergent evaluation model that involves multiple participants—learners, instructors, instructional designers and media developers. Each of these groups offers feedback throughout the development of a learning object. Ultimately a report is produced that represents multiple values and needs. A number of studies evaluating learning objects gather information from multiple sources (for example, Kenny *et al.*, 1999; Bradley & Boyle, 2004; Krauss & Ally, 2005; MacDonald *et al.* 2005), although the formal convergence of participant values advocated by Nesbit *et al.* (2002) is not pursued. The convergent evaluation model is somewhat limited by the typically small number of participants giving feedback. In other words, the final evaluation may not be representative of what a larger population might observe or experience.

Instructional design. Pedagogically focused designers of learning objects have emphasized principles of instructional design, interactivity, clear instructions, formative assessment and solid learning theory (for example, Baruque & Melo, 2004; Bradley & Boyle, 2004; Cochrane, 2005; Krauss & Ally, 2005). However, there is relatively little research on the design principles as they apply to learning objects (Williams, 2000; Cochrane, 2005). Recommendations for specific design characteristics are proposed but are rarely evaluated (Downes, 2001; Krauss & Ally, 2005). It is more typical to collect open-ended, informal feedback on learning objects without reference to specific instructional design characteristics that might enhance or reduce learning performance (for example, Kenny *et al.*, 1999; Bradley & Boyle, 2004; Krauss & Ally, 2005).

Methodological issues

At least six key observations are noteworthy with respect to methods used to evaluate learning objects. First, most studies offer clear descriptions of the learning objects used; however, considerable variation exists in content. Learning objects examined included drill-and-practice assessment tools (Adams *et al.*, 2004) or tutorials (Jaakkola & Nurmi, 2004), video case studies or supports (Kenny *et al.*, 1999; MacDonald *et al.*, 2005), general web-based multimedia resources (Van Zele *et al.*, 2003) and self-contained interactive tools in a specific content area (Bradley & Boyle, 2004; Cochrane, 2005). The content and design of a learning object needs to be considered when examining quality and learning outcomes (Jaakkola & Nurmi, 2004; Cochrane, 2005).

Second, a majority of researchers use multiple sources to evaluate learning objects, including surveys, interviews or email feedback from students and faculty, tracking the use of learning objects by students, think-aloud protocols and learning outcomes (for example, Kenny *et al.*, 1999; Bradley & Boyle, 2004; Krauss & Ally, 2005; MacDonald *et al.* 2005).

Third, most evaluation papers focus on single learning objects (Kenny *et al.*, 1999; Adams *et al.*, 2004; Bradley & Boyle, 2004; Krauss & Ally, 2005; MacDonald *et al.*, 2005); however, using an evaluation tool to compare a range of learning objects can provide useful insights. For example, Cochrane (2005) compared a series of four learning objects based on general impressions of reusability, interactivity and pedagogy, and found that different groups valued different areas. Also, Jaakkola and Nurmi (2004) compared drill-and-practice versus interactive learning objects and found the latter to be significantly more effective in improving overall performance.

Fourth, with the exception of Jaakkola and Nurmi's (2004) unpublished but well-designed report, the evaluation of learning objects has been done exclusively in higher education. Furthermore, sample size has been typically small and/or poorly described (Van Zele *et al.*, 2003; Adams *et al.*, 2004; Cochrane, 2005; Krauss & Ally, 2005; MacDonald *et al.*, 2005), making it difficult to extend any conclusions to a larger population.

Fifth, while most evaluation studies reported that students benefited from using learning objects, the evidence is based on loosely designed assessment tools with no validity or reliability (Kenny *et al.*, 1999; Van Zele *et al.*, 2003; Bradley & Boyle, 2004; Krauss & Ally, 2005). Finally, only 2 of the 11 evaluation studies (Kenny *et al.*, 1999; Van Zele *et al.*, 2003) examined in Kay and Knaack's (submitted) review of the learning object literature used formal statistics. The majority of studies relied on descriptive data and anecdotal reports to assess the merits of learning objects. The lack of reliability and validity of evaluation tools and an absence of statistical rigour make it difficult to have full confidence in the results presented to date.

In summary, previous methods used to evaluate learning objects have incorporated clear descriptions of the tools used and multiple sources of data collection, although limitations are evident with respect to sample size, representative populations, reliability and validity of data collection tools and the use of formal statistics.

Purpose

The purpose of this study was to explore a learning-based approach for evaluating learning objects. Based on a detailed review of studies looking at the evaluation of learning objects, the following practices were followed:

- a large, diverse, sample of secondary school students was used;
- reliability and validity estimates were calculated;

- formal statistics were used where applicable;
- both formative and summative evaluations were employed;
- specific learning objects features based on instructional design research were examined;
- a range of learning objects was tested; and
- evaluation criteria focused on the learner, not the technology.

Method

Sample

Students. The sample consisted of 221 secondary school students (104 males, 116 females, one missing data), 13–17 years of age, in grade 9 ($n = 85$), grade 11 ($n = 67$) and grade 12 ($n = 69$) from 12 different high schools and three boards of education. The students were obtained through convenience sampling.

Teachers. A total of 30 teachers (nine experienced, 21 pre-service) participated in the development of the learning objects. The team breakdown by subject area was eight for biology (two experienced, six pre-service), five for chemistry (two experienced, three pre-service), five for computer science (one experienced, four pre-service), five for physics (one experienced, four pre-service) and seven for mathematics (three experienced, four pre-service).

Learning objects. Five learning objects in five different subject areas were evaluated by secondary school students. Seventy-eight students used the mathematics learning object (grade 9), 40 used the physics learning object (grades 11 and 12), 37 used the chemistry learning object (grade 12), 34 used the biology learning object (grades 9 and 11) and 32 used the computer science learning object (grades 11 and 12). All learning objects can be accessed online (http://education.uoit.ca/learningobjects). All five learning objects met the criteria established by the definition of a learning object provided for this paper. They were interactive, web-based and enhanced concept formation in a specific area through graphical supports and scaffolding. A brief description for each is provided below.

Mathematics. This learning object (slope of a line) was designed to help grade 9 students explore the formula and calculations for the slope of a line. Students used their knowledge of slope to navigate a spacecraft through four missions. As the missions progressed from level one to level four, less scaffolding was provided to solve the mathematical challenges.

Physics. This learning object (relative velocity) helped grade 11 and grade 12 students explore the concept of relative velocity. Students completed two case-study questions, and then actively manipulated the speed and direction of a boat, along with the river speed, to see how these variables affect relative velocity.

Biology. This learning object (Mendelian genetics) was designed to help grade 11 students investigate the basics of Mendel's genetics relating the genotype (genetic trait) with the phenotype (physical traits) including monohybrid and dihybrid crosses. Students had a visual scaffolding to predict and complete Punnett squares. Each activity finished with an assessment.

Chemistry. This grade12-oriented learning object (Le Chatelier's Principle 1) demonstrated the three stresses (concentration, temperature and pressure change) that can be imposed to a system at chemical equilibrium. Students explored how equilibrium shifts related to Le Chatelier's Principle. Students assessed their learning in a simulated laboratory environment by imposing changes to equilibrated systems and predicting the correct outcome.

Computer Science. This learning object (Boolean logic) was designed to teach grade 10 or grade 11 students the six basic logic operations (gates)—AND, OR, NOT, XOR (exclusive OR), NOR (NOT-OR) and NAND (NOT-AND)—through a visual metaphor of water flowing through pipes. Students selected the least number of inputs (water taps) needed to get a result in the single output (water holding tank) to learn the logical function of each operation.

Developing the learning objects

The design of the learning objects was based on the following principles. First, the learning objects were created at the grassroots level by pre-service and in-service teachers. Wiley (2000) maintained that learning objects need to be sufficiently challenging, so in-service teachers in this study were asked to brainstorm about and select areas where their students had the most difficulty. Second, the learning objects were designed to be context rich; however, they focused on relatively specific topic areas that could be shared by different grades. Reusability, while important, was secondary to developing meaningful and motivating problems. This approach is supported by a number of learning theorists (for example, Larkin, 1989; Sternberg, 1989; Lave & Wenger, 1991). Third, the learning objects were both interactive and constructivist in nature. Students interacted with the computer, but not simply by clicking 'next, next, next'. They had to construct solutions to genuine problems. Fourth, the 'octopus' or resource model proposed by Wiley *et al.* (2004) was used. The learning objects were designed to support and reinforce understanding of specific concepts. They were not designed as stand alone modules that could teach concepts. Finally, the learning objects went through many stages of development and formative evaluation, including a pilot study involving secondary school students (see Table 3).

Procedure

Pre-service teachers (guided by an experienced mentor) and in-service teachers administered the survey to their classes after using one of the learning objects within the context of a lesson. Students were told the purpose of the study and asked to give written consent if they wished to volunteer to participate. Teachers and teacher candidates were instructed to use the learning object as authentically as possible. Often the learning object was used as another teaching tool within the context of a unit. After one period of using the learning object (approximately 70 minutes), students were asked to fill out a survey (see Appendix).

Data sources

The data for this study were gathered using four items based on a seven-point Likert scale, and two open-ended questions (see Appendix). The questions yielded both quantitative and qualitative data.

Quantitative data. The first construct consisted of items one to four (Appendix), and was labelled 'perceived benefit' of the learning object. The internal reliability estimate was 0.87 for this scale. Criterion related validity for perceived benefit score was assessed by correlating the survey score with the qualitative ratings (item 9—see scoring below). The correlation was significant (0.64; $p < 0.001$).

Qualitative data—perceived benefits of learning objects. Item six (Appendix) asked students whether the learning object was beneficial. Two-hundred and twenty-five comments were made and categorized according to nine post-hoc categories (Table 1). Each comment was then rated on a five-point Likert scale (–2 = very negative, –1 = negative, 0 = neutral, 1 = positive, 2 = very positive). Two raters assessed all comments made by students and achieved inter-rater reliability of 0.72. They then met, discussed all discrepancies and attained 100% agreement.

Qualitative data—learning object quality. Item five (Appendix) asked students what they liked and did not like about the learning object. A total of 757 comments were written down by 221 students. Student comments were coded based on well-established principles of instructional design. Thirteen categories are presented with examples and references in Table 2. In addition, all comments were rated on a five-point Likert scale (–2 = very negative, –1 = negative, 0 = neutral, 1 = positive, 2 = very positive).

Table 1. Coding scheme for assessing perceived benefits of learning objects (item six, Appendix)

Reason category	Criteria	Sample student comments
Timing	When the learning object was introduced in the curriculum	'I think I would have benefited more if I used this program while studying the unit' 'It didn't benefit me because that particular unit was over. It would have helped better when I was first learning the concepts'
Review of basics/ reinforcement	Refers to reviewing, reinforcing concept, practice	'going over it more times is always good for memory' 'it did help me to review the concept and gave me practise in finding the equation of a line'
Interactive/hands on/ learner control	Refers to interactive nature of the process	'I believe I did, cause I got to do my own pace … I prefer more hands on things (like experiments)' 'Yes, it helped because it was interactive'
Good for visual learners	Refers to some visual aspect of the process	'I was able to picture how logic gates function better through using the learning object' 'I found it interesting. I need to see it'
Computer based	Refers more generally to liking to work with computers	'I think that digital learning kind of made the game confusing' 'I think I somewhat did because I find working on the computer is easier than working on paper'
Fun/interesting	Refers to process being fun, interesting, motivating	'I think I learned the concepts better because it made them more interesting' 'I think I did. The learning object grasped my attention better than a teacher talking non-stop'
Learning related	Refers to some aspect of the learning process	'I don't think I learned the concept better' 'It did help me teach the concept better'
Clarity	Refers to the clarity of the program and/or the quality of instruction	'I think it was very confusing and hard to understand' 'Yes, this helped me. It made it much clearer and was very educational'
Not good at subject	Refers to personal difficulties in subject areas	'No, to be honest it bothered me. In general I don't enjoy math and this did not help'
Compare with other method	Compared with other teaching method/strategy	'Yes, because it … is better than having the teacher tell you what to do' 'Would rather learn from a book'
No reason given		'I didn't benefit from any of it' 'Yes'

Table 2. Coding scheme for assessing learning object quality (item five, Appendix)

Category (references)	Criteria	Sample student comments
Organization/layout (for example, Madhumita, 1995; Koehler & Lehrer, 1998)	Refers to the location or overall layout of items on the screen	'Sometimes we didn't know where/what to click'
		'I found that they were missing the next button'
		'Easy to see layout'
		'[Use a] full screen as opposed to small box'
Learner control over interface (for example, Akpinar & Hartlet, 1996; Kennedy & McNaught, 1997; Bagui, 1998; Hanna *et al.*, 1999)	Refers the control of the user over specific features of the learning object including pace of learning	'[I liked] that it was step by step and I could go at my own pace'
		'I liked being able to increase and decrease volume, temperature and pressure on my own. It made it easier to learn and understand'
		'It was too brief and it went too fast'
Animation (for example, Oren, 1990; Gadanidis *et al.*, 2003; Sedig & Liang, 2006)	Refers specifically to animation features of the program	'You don't need all the animation. It's good to give something good to look at, but sometimes it can hinder progress'
		'I liked' the fun animations'
		'Like how it was linked with little movies … demonstrating techniques'
		'I liked the moving spaceship'
Graphics (for example, Oren, 1990; Gadanidis *et al.*, 2003; Sedig & Liang, 2006)	Refers to graphics (non-animated of the program), colours, size of text	'The pictures were immature for the age group'
		'I would correct several mistakes in the graphics'
		'The graphics and captions that explained the steps were helpful'
		'Change the colours to be brighter'
Audio (for example, Oren, 1990; Gadanidis *et al.*, 2003; Sedig & Liang, 2006)	Refers to audio features	'Needed a voice to tell you what to do'
		'Needs sound effects'
		'Unable to hear the character (no sound card on computers)'

Table 2. *(continued)*

Category (references)	Criteria	Sample student comments
Clear instructions (for example, Jones *et al.*, 1995; Kennedy & McNaught, 1997; Macdonald *et al.*, 2005)	Refers to clarity of instructions before feedback or help is given to the user	'Some of the instruction were confusing'
		'I … found it helpful running it through first and showing you how to do it'
		'[I needed] … more explanations/Clearer instructions'
Help features (for example, Jones *et al.*, 1995; Kennedy & McNaught, 1997; Macdonald *et al.*, 2005)	Refers to help features of the program	'The glossary was helpful'
		'Help function was really good'
		'Wasn't very good in helping you when you were having trouble … I got more help from the teacher than it'
Interactivity (for example, Akpinar & Hartley, 1996; Kennedy & McNaught, 1997; Bagui, 1998; Hanna *et al.*, 1999)	Refers to general interactive nature of the program	'Using the computer helped me more for genetics because it was interactive'
		'I like that it is on the computer and you were able to type the answers'
		'I liked the interacting problems'
Incorrect content/errors	Refers to incorrect content	'There were a few errors on the sight'
		'In the dihybrid cross section, it showed some blond girls who should have been brunette'
Difficulty/challenge levels (for example, Savery & Duffy, 1995; Hanna *et al.*, 1999)	Was the program challenging? Too easy? Just the right difficulty level?	'Make it a bit more basic'
		'For someone who didn't know what they were doing, the first few didn't teach you anything but to drag and drop'
		'I didn't like how the last mission was too hard'

Table 2. *(continued)*

Category (references)	Criteria	Sample student comments
Useful/informative (for example, Sedig & Liang, 2006)	Refers to how useful or informative the learning object was	'I like how it helped me learn'
		'I found the simulations to be very useful'
		'[The object] has excellent review material and interesting activities'
		'I don't think I learned anything from it though'
Assessment (Atkins, 1993; Sedighian, 1998; Zammit, 2000; Kramarski & Zeichner, 2001; Wiest, 2001)	Refers to summative feedback/evaluation given after a major task (as opposed to a single action) is completed	No specific comments offered by students
Theme/motivation (Akpibar & Hartley, 1996; Harp & Mayer, 1998)	Refers to overall theme and/or motivating aspects of the learning object	'Very boring. Confusing. Frustrating'
		'Better than paper or lecture—game is good!'
		'I liked it because I enjoy using computers, and I learn better on them'

Two raters assessed the first 100 comments made by students and achieved inter-rater reliability of 0.78. They then met, discussed all discrepancies and attained 100% agreement. Next the raters assessed the remaining 657 comments with an inter-rated reliability of 0.66. All discrepancies were reviewed and 100% agreement was again reached.

Key variables

The key variables used to evaluate learning objects in this study were the following:

- perceived benefit (survey construct of four items; Appendix);
- perceived benefit (content analysis of open-ended question based on post-hoc structured categories; Table 1);
- quality of learning objects (content analysis of open-ended response question based on 13 principles of instruction design; Table 2); and
- learning object type (biology, computer science, chemistry, physics, mathematics).

Results

Formative evaluation

Table 3 outlines nine key areas where formative analysis of the learning objects was completed by pre-service and in-service teachers, students, a media expert or an external learning object specialist. Eight of these evaluations occurred before the summative evaluation of the learning object. Numerous revisions were made throughout the development process. A final focus group offered systematic analysis of where the learning objects could be improved.

The focus groups also reported a series of programming changes that would help improve the consistency and quality of the learning objects (see Table 4). It is important to note that the changes offered for chemistry, biology, and computer science learning objects were cosmetic, whereas those noted for mathematics and physics were substantive, focusing on key learning challenges. Mathematics and physics comments included recommendations for clearer instructions, which is consistent with student evaluations where chemistry and biology learning objects were rated significantly better than mathematics and physics objects (see Table 4).

The positive impact of formative assessment in creating effective learning objects is reflected by a majority of students reporting that the learning objects were useful (see detailed results below).

The remaining results reported in this study are summative evaluations collected from students who actually used the learning objects in a classroom.

Perceived benefit of learning object—survey construct

Based on the average perceived benefit rating from the survey (items one to four, Appendix), students felt the learning object was more beneficial than not (mean =

Table 3. Timeline for formative analysis used in developing the learning objects

Step	Time	Description
Mock prototyping	September 2004 (two hours)	Subject team introduced to learning objects by creating paper-based prototype; Member from each team circulated and gave feedback on clarity and design
Prototyping and usability	November 2004 (one and a half days)	Subject teams produced detailed paper prototype of their learning objects. Every two hours subject teams were asked to circulate around the room, and give feedback on other group's learning object designs. It is not uncommon for 10–20 versions of the paper-prototype to emerge over the span of this one-and-a-half-day workshop
Electronic prototype	December 2004	One team member creates PowerPoint prototype of learning object. Throughout this process, feedback was solicited from other team members. Edits and modifications were made through an online discussion board where various versions of the prototype were posted and comments from team members were discussed
Programming learning object	January 2005	A Flash programmer/multimedia designer sat down with each group and observed their electronic prototype. He discussed what challenges they would have and different strategies for getting started in Flash
Team formative evaluation	February 2005 (half day)	Subject teams evaluate each other's Flash versions of learning objects. Each team had approximately 15 minutes to go through their learning object, describe interactivity components and highlight sections that each member had done. The entire learning object group provided feedback during and after each presentation
Pilot test	February 2005 (one day)	Learning objects pilot tested on 40 volunteer students
External formative evaluation	February 2005 (half day)	CLOE expert provides provided one-to-one guidance and feedback for improving the learning objects
Revision plan (before summative evaluation)	February 2005 (half day)	Subject teams digest student and expert feedback and make plan for further revisions
Revision plan (after summative evaluation	April 2005	Subject teams brought together to evaluate implementation of learning objects future revisions (see Table 5)

Table 4. Proposed programming changes for learning by subject area

Learning object	Proposed changes
Biology	Integrate dihybrid activity.
	In dihybrid Punnett square #1:
	Blue squares updated to question marks.
	Prompt for next button removed.
	In dihybrid analysis #1:
	Click and drag too repetitive.
	Eye colour difficult to see in dihybrid section.
	Fix credits
	Monohybrid—'What is monohybrid' tab:
	Remove word 'dominant' from heterozygous.
	Monohybrid Punnett #1:
	'The off spring…'—should be on one line.
	Dihybrid Punnett #1:
	Words in combination box on one line.
Chemistry	Give example of catalyst/noble gas in year 3.
	'Correct' change text colour to green or blue.
	Update credits.
	Link to activities in each year.
	Simulation.
	Remove title from certificate frame.
	Size of screen—too small
Computer science	Buttons are active and hidden—e.g., upper left and main choice buttons hidden behind instructions and help screen
	Level 2—should there be a short pipe under the second-last OR gate?
	Level 2—no 'unsuccessful' message
	Level 3—no 'unsuccessful' message
	Level 5—incorrect message if choose right-most two taps (message also appears twice)
	Level 5—no 'unsuccessful' message
	Level 6—incorrect message if choose either of the right-most taps
	Level 6—no 'unsuccessful' message
	On level 6, above NAND, there is no end to the pipes
	General—change pipe colour (to silver–grey?) and the 'on' tap colour to green (to match text instructions and feedback from users)
	About screen—bump up the version number (v1.4?, v1.5?)
	Teacher info/expectations à 'Ontario Curriculum Unit Planner' should be changed to 'the content and intentions of the published Ontario curriculum'
	Teacher info/prerequisite—same wording as above
	The big grey box at the left with all the mouse-over help—put this on the right and make it a water tank, and then feed the flow from this—it would make it a useful part of the metaphor, rather than a big help box taking up a large part of the screen

Table 4. *(continued)*

Learning object	Proposed changes
Mathematics	Make help more obvious. Have a bubble? Bubbles for areas of the screen (console and intro to the screen).
	Press 'Enter' on the keyboard instead of 'next' on screen (when prompted for text).
	Mission 2—students didn't know that they needed to do the calculations on their own using pencil and paper. Instructions need to be more explicit.
	'Instruction' font size and colour are too small and too dark.
	Options to go back to other missions, and when they get to the end, more clarity as to what or where they will go → more missions or choices.
	Variety of scenarios (missions).
	Display the equation of the line drawn from 'planet' to 'planet'.
Physics	Program locked up at times.
	Instructions are not obvious.
	Screen resolution problems.
	Labels inconsistent.
	No defined learning objects for case 3.
	Boat can disappear!?
	Better used as a demonstration tool or as a problem-solving simulation.
	Cannot teach the concept in isolation from a teacher.

4.8, standard deviation = 1.5; scale ranged from 1 to 7). Fourteen per cent of all students ($n = 30$) disagreed (average score of 3 or less) that the learning object was of benefit, whereas 55% ($n = 122$) agreed (average score of 5 or more) that it was useful.

Perceived benefit of learning object—content analysis

The qualitative comments (item six, Appendix) based on the post-hoc categories outlined in Table 1 supported the survey results. Twenty-four per cent of the students ($n = 55$) felt the overall learning object was not beneficial; however, 66% ($n = 146$) felt it did provide benefit.

A more detailed examination indicated that the motivational, interactive and visual qualities were most important to students who benefited from the learning object. Whether they learned something new was also cited frequently and rated highly as a key component. Presenting the learning object after the topic had already been learned and poor instructions were the top two reasons given by students who did not benefit from the learning object (Table 5).

Quality of learning object—content analysis

Overview. Students were relatively negative with respect to their comments about learning object quality (item five, Appendix). Fifty-seven per cent of all comments

Table 5. Mean ratings for reasons given for perceived benefits of learning objects (item nine)

Reason	*n*	Mean	Standard deviation
Fun/interesting	17	1.35	0.74
Visual learners	33	1.24	0.84
Interactive	30	1.17	1.34
Learning related	37	0.81	1.13
Good review	60	0.80	1.04
Computer based	5	0.20	1.40
Compare with another method	24	0.00	1.18
Timing	21	−0.29	1.19
Clarity	33	−0.55	0.00
Not good at subject	3	−1.35	0.38

were either very negative ($n = 42$, 6%) or negative ($n = 392$, 52%), whereas only 42% of the students made positive ($n = 258$, 34%) or very positive ($n = 57$, 8%) statements about learning object quality.

Categories. An analysis of categories evaluating learning object quality (see Table 2 for descriptions) identified animation, interactivity and usefulness as the highest rated areas, and audio, correct information, difficulty, clarity of instructions and help functions as the lowest rated areas. Table 6 presents the means and standard deviation for all categories assessing the quality of learning objects.

A one-way analysis of variance (ANOVA) comparing categories of learning object quality was significant ($p < 0.001$). Audio, correct information and difficulty were

Table 6. Mean ratings for categories evaluating learning object quality

Category	*n*	Mean	Standard deviation
Animations	27	0.81	0.74
Interactivity	47	0.66	0.84
Useful	39	0.51	1.34
Assessment	9	0.44	1.13
Graphics	84	0.25	1.04
Theme/motivation	125	0.12	1.40
Organization	34	−0.06	1.18
Learner control	75	−0.12	1.19
Help functions	42	−0.43	1.02
Clear instructions	138	−0.61	0.95
Difficulty	107	−0.67	0.81
Information correct	17	−1.00	0.00
Audio	13	−1.15	0.38

rated significantly lower than animations, interactivity and usefulness (Scheffé post-hoc analysis, $p < 0.05$).

Categories—likes only. One might assume that categories with mean ratings close to zero are not particularly important with respect to evaluation. However, it is possible that a mean of zero could indicate an even split between students who liked and disliked a specific category. Therefore, it is worth looking at what students liked about the learning objects, without dislikes, to identify polar 'hot spots'. A comparison of means for positive comments confirmed that usefulness (mean = 1.33) was still important, but that theme and motivation (mean = 1.35), learner control (mean = 1.35) and organization of the layout (mean = 1.20) also received high ratings. These areas had mean ratings that were close to zero when negative comments were included (see Table 5). This indicates than students had relatively polar attitudes about these categories.

Categories—dislikes only. A comparison of means for negative comments indicated that usefulness (mean = –1.33) remained important; however, theme and motivation (mean = –1.32) was also perceived as particularly negative. Students appeared to either like or dislike the theme or motivating qualities of the learning object.

Correlation between quality and perceived benefit scores. Theme and motivation ($r = 0.45$, $p < 0.01$), the organization of the layout ($r = 0.33$, $p < 0.01$), clear instructions ($r = 0.33$, $p < 0.01$) and usefulness ($r = 0.33$, $p < 0.01$) were significantly correlated with the perceived benefit survey (items one to four, Appendix).

Learning object type

A multivariate ANOVA was used to examine differences among learning object types (subject) with respect to perceived benefits and quality of learning object (Table 7). Significant differences among learning objects were observed for perceived benefit

Table 7. Multivariate ANOVA for learning object quality, perceived benefits (survey), and perceived benefits (content analysis) for learning object type

Source	Degrees of freedom	Sum of squares	Mean square	*F* value	Scheffé post-hoc analysis
Learning quality (item five)	4	18.0	4.5	13.3*	Biology, computer science, chemistry > mathematics, physics**
Perceived benefits (survey)	4	54.2	13.5	13.3*	Biology, computer science, chemistry > mathematics, physics**
Perceived benefits (content analysis)	4	1942.5	485.6	18.3*	Biology, computer science, chemistry > mathematics, physics**

*$p < 0.001$, ** $p < 0.05$.

(survey and content analysis $p < 0.001$) and learning object quality ($p < 0.001$). An analysis of contrasts revealed that the chemistry, biology and computer science learning objects were rated significantly higher with respect to perceived benefit and learning object quality ($p < 0.05$).

While the number of observations was too small to make comparisons among post-hoc categories for perceived benefit (Table 2), a series of ANOVAs was run comparing mean learning objects ratings of categories used to assess learning object quality. A majority of the categories revealed no significant effect, although three areas showed significant differences among learning objects: learner control, clear instructions, and theme/motivation. The chemistry learning object was rated significantly higher than the mathematics and biology learning objects with respect to learner control ($p < 0.001$). The chemistry and biology learning objects were rated significantly higher than the mathematics and physics learning objects with respect to clear instructions ($p < 0.001$). Finally, the computer science learning object was rated significantly higher than the mathematics learning object with respect to theme/motivation ($p < 0.001$). These results are partially compromised because all learning objects were not experienced by students from each grade.

Feedback from learning object teams

With respect to the positive qualities of learning objects, two key themes emerged in the focus groups for all five learning objects: graphics and interactivity. These were to the two qualities that students liked best. Regarding areas for improvement, feedback varied according to the specific learning object used. The biology group reported that students wanted better audio and more challenges. The chemistry group noted that teacher support was necessary for the learning objects and that some instructions were unclear. The computer science group commented that students liked the learning object but wanted more difficult circuits. The mathematics group felt the success of the learning object was tied closely to when the concept was taught and in what format (group versus individual). Finally, the physics group observed that a number of bugs and obscure instructions slowed students down.

Discussion

The purpose of this study was to explore a learning-based approach for evaluating learning objects. Key issues emphasized were sample population, reliability and validity, using formal statistics where applicable, incorporating both formative and summative evaluations, examining specific learning objects features based on instructional design research, testing of a range of learning objects, and focusing on the learner, not the technology.

Sample population

The population in this study is unique compared with previous evaluations of learning objects. A large, diverse, sample of secondary school students was used to provide feedback, instead of a relatively small, vaguely defined, higher education group. Larger, more diverse populations are needed to ensure confidence in the final results. The sample in this study permitted a more in-depth analysis of specific learning object features that affected learning.

Reliability and validity

This study is unique in attempting to develop a reliable and valid metric to evaluate the benefits and specific impact of a wide range of learning object qualities. The perceived-benefits scale proved to be reliable and valid. The quality scale was also reliable and partially validated by focus group data gathered from teachers after the summative evaluation. The coding scheme (see Table 2) based on sound principles of instructional design with 100% inter-rater reliability was particularly useful in isolating and identifying salient qualities of learning objects. Overall, the evaluation tool used in this study provided a reasonable foundation with which to assess the impact of learning objects.

Data analysis

While descriptive analysis proved to be valuable in providing an overview of perceived benefits and quality of the learning objects tested, inferential statistics provided useful information on the relationship between perceived benefits and learning quality, as well as the individual learning qualities deemed to be most important by students. The combination of descriptive and inferential statistics, not regularly seen in previous learning object research, is critical to establishing a clear, reliable, understanding of how learning objects can be used as effective teaching tools.

Formative and summative feedback

Formative assessment was critical in this study for developing a set of five workable learning objects in a relatively short time period (eight months). This approach is consistent with Williams (2000) and Cochrane's (2005) philosophy of design. In addition, formative assessment helped to validate the summative evaluation results reported by students. In the current study, summative evaluation based on theoretical grounded instructional design principles provided detailed pedagogical information lacking in previous learning object research, where informal, general and anecdotal results were the norm (for example, Kenny *et al.*, 1999; Bradley & Boyle, 2004; Krauss & Ally, 2005). While most evaluation studies report that learning objects are positively received by students and faculty, it is difficult to determine the qualities in a learning object that contribute to or inhibit learning. The metric used in the current study opens the door to a more informative discussion about what learning object features are beneficial.

Comparing learning objects

The comparison of five different learning objects in this study demonstrated that even when learning objects are designed to be similar in format, considerable variation exists with respect to perceived benefit and quality. This result is consistent with Cochrane (2005) and Jaakkola and Nurmi (2004). An effective evaluation tool must account for the wide range of learning objects that have been and are currently being produced. For the five objects in this study, learner control, clear instructions and theme were the key distinguishing features. It is important to note that different features might take precedence for other learning object designs. For example, interactivity might be more important when tutorial-based learning objects are compared with tool-based learning objects.

Metric based on principles of instructional design

Perhaps the strongest element of the evaluation model presented in this study is the use of well-established instructional design principles to code feedback from students. As stated earlier, even though the developers of learning objects have emphasized features such as interactivity, clear instructions and solid learning theory in the design process (Bradley & Boyle, 2004; Cochrane, 2005; Macdonald *et al.* 2005; Sedig & Liang, 2006), evaluation tools have opted for a more general perspective on whether a learning object is effective. It is argued that a finer metric is needed to identify features that have a significant impact on learning. This allows educators to supplement problems areas when using learning objects and gives designers a plan for future modifications. In the current study, organization of the layout, learner control, clear instructions and theme were critical hotspots where the use of learning objects enhanced or inhibit learning. If a learning object provides clear instructions, is well organized, is easy to use and has a motivating theme, secondary school students are more likely feel they have benefited from the experience. These results match the qualitative feedback reported by Cochrane (2005) and MacDonald *et al.* (2005) for higher education students. Finally, formative feedback from focus groups helps translate statistical differences observed into concrete suggestions for change.

Focusing on learner, not technology

The learning-based approach used in the current study permits designers and educators to answer the question of 'what features of a learning object provide the most educational benefit to secondary school students?' The evidence suggests that students will benefit more if the learning object has a well-organized layout, is interactive, visual representations are provided that make abstract concepts more concrete, instructions are clear and the theme is fun or motivating.

Overall, secondary school students appear to be relatively receptive to using learning objects. While almost 60% of the students were critical about one or more learning object features, roughly two-thirds of all students perceived learning objects as beneficial because they were fun, interactive, visual and helped them learn. Students who did not benefit felt that learning objects were presented at the wrong time (e.g. after they had already learned the concept) or that the instructions were not clear enough. Interestingly, student feedback, both positive and negative, emphasized learning. While reusability, accessibility and adaptability are given heavy emphasis in the learning object literature, when it comes to the end user, learning features appear to be more important.

Future research

This study was a first step in developing a pedagogically based evaluation model for evaluating learning objects. While the study produced useful information for educators, designers and researchers, there are at least five key areas that could be addressed in future research. First, a set of pre-test and post-test content questions is important to assess whether any learning actually occurred. Second, a more systematic survey requiring students to rate all quality and benefit categories (Tables 1 and 2) would help to provide more comprehensive assessment data. Third, details about how each learning object is used are necessary to open up a meaningful dialogue on the kind of instructional wrap that is effective with learning objects. Fourth, use of think-aloud protocols would be helpful to examine actual learning processes while learning objects are being used. Finally, a detailed assessment of computer ability, attitudes, experience and learning styles of students might provide insights about the impact of individual differences on the use of learning objects.

Summary

Based on a review of the literature, it was argued that a learning-based approach for evaluating learning objects was needed. Limitations in previous evaluation studies were addressed using a large, diverse, sample, providing reliability and validity estimates, using formal statistics to strengthen any conclusions made, incorporating both formative and summative evaluations, examining specific learning objects features based on principles of instructional design, and testing of a range of learning objects. It was concluded that the learning-based approach produced useful and detailed information for educators, designers and researchers about the impact of learning objects in the classroom.

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Appendix. Learning object survey

	Strongly Disagree 1	Disagree 2	Slightly Disagree 3	Neutral 4	Slightly Agree 5	Agree 6	Strongly Agree 7
1. The learning object has some benefit in terms of providing me with another **learning strategy/another tool**.	1	2	3	4	5	6	7
2. I feel the learning object did **benefit** my **understanding** of the subject matter's concept/principle.	1	2	3	4	5	6	7
3. I **did not benefit** from using the learning object.	1	2	3	4	5	6	7
4. I am interested in using the **learning object again**.	1	2	3	4	5	6	7

5. You used a digital learning object on the computer. Tell me about this experience when you used the object.

   a) What did you like? (found helpful, liked working with, what worked well for you)

   b) What didn't you like? (found confusing, or didn't like, or didn't understand)

6. Do you think you benefited from using this particular learning object? Do you think you learned the concept better? Do you think it helped you review a concept you just learned? Why? Why not?