STUDENT DEVELOPMENT PROCESS OF DESIGNING AND IMPLEMENTING EXPLORATORY AND LEARNING OBJECTS

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In 2001 a core undergraduate program, called Mathematics Integrated with Computers and Applications (MICA) *was introduced in the Department of Mathematics at Brock University, Canada. In this program that integrates evolving technologies, students complete major projects that require the design and implementation of 'Exploratory and Learning Objects' (ELO). In this paper, we propose schematic representations and descriptions of the student development process as s/he completes an ELO project. We highlight the important role that ELO interfaces play in this development process.*

Keywords: *Exploratory and Learning Objects (ELO); student development process; students designing and implementing ELO; university mathematics education.*

INTRODUCTION

There have been a number of publications (Muller, 1991, 2001; Muller & Buteau, 2006; Buteau & Muller, 2006; Pead et al, 2007; Muller et al., forthcoming) about the long-term implementation of evolving technology use in undergraduate mathematics education at Brock University (Canada) that started in the early 80s. The most recent development is the 2001 implementation of the core undergraduate mathematics program called *Mathematics Integrated with Computers and Applications* (MICA). Two of the program aims are to (1) develop mathematical concepts hand in hand with computers and applications; and (2) encourage student creativity and intellectual independence (Brock Teaching, 2001). Three innovative core courses, called *MICA I, II, III*, were implemented in addition to a review of all traditional courses to incorporate the MICA program aims. Results of a 2006 MICA student survey and an enrolment analysis covering the years 2001 to 2006 are reported in Ben-El-Mechaiekh et al. (2007). Highlights include

> Students overall rated the use of technology in their mathematics courses as positively beneficial (77.74% of responses; 79.36% when restricted to mathematics majors). (p.10)

and, furthermore,

> ... students overwhelmingly rated the use of technology in [MICA] courses as [positively] beneficial (91.13% of responses) (p.9)

In this paper proposal, we focus on one of the major student activities in the MICA courses, namely their designing, implementing (VB.net, Maple, C++), and using of interactive and dynamic computer-based environments, called Exploratory and

Learning Objects (ELO). By Exploratory Object (EO) and Learning Object (LO), we mean the following.

> *An Exploratory Object is an interactive and dynamic computer-based model or tool that capitalizes on visualization and is developed to explore a mathematical concept or conjecture, or a real-world situation*
>
> and,
>
> *A Learning Object is an interactive and dynamic computer-based environment that engages a learner through a game or activity and that guides him/her in a stepwise development towards an understanding of a mathematical concept.* (Muller et al., forthcoming, p.5)

To illustrate these objects, we provide without comment three examples of original student ELO projects that can be accessed at (MICA Student Projects website, n.d.): (1) *Structure of the Hailstone Sequences* EO by first-year student Colin Phipps for the investigation of a mathematical conjecture; (2) *Running in the Rain* EO by second-year students Matthew Lillie and Kylie Maheu for the investigation of a real-world situation; and (3) *Exploring the Pythagorean Theorem* LO by first-year student Lindsay Claes for the learning of a school mathematical concept.

In previous publications, we have elaborated how the MICA I course is designed to progressively bring the students to acquire the skills and understanding required for the development of ELOs (Muller & Buteau, forthcoming). In brief, as the course progresses, our students are guided through each step in the development process of ELOs that we describe in the next section of this paper. We have also explained that this requires a significant change in the teaching paradigm of faculty involved in these courses, and motivates a change in attitude in the students about learning and doing mathematics with technology at the university level (Muller et al., forthcoming). And also, we have argued that learning activities in the MICA program accelerates students' growth towards independence in doing mathematics (Buteau & Muller, 2006).

In this paper we propose a first attempt at defining a structure for the student development process in their activity of designing, implementing, and using an ELO. These final MICA projects are completed individually or in pairs selecting a topic of their own choice. We also briefly discuss the role of interfaces in the student development of an ELO. As in the past, we, as mathematicians in a mathematics department, look forward to receiving constructive feedback from mathematics educators. We hope that the presentation of our innovative student learning activities, as part of the systemic integration of technology in our university mathematics curriculum, will instigate educational research questions on learning mathematics with use of technology in tertiary education.

STUDENT DEVELOPMENT PROCESS OF EXPLORATORY AND LEARNING OBJECTS

In what follows, we suggest schematic representations of the development process for ELOs. Even though the schematic representations are worded generally, in their descriptions we focus on students in MICA courses.

Development Process of an Exploratory Object to Investigate a Conjecture

We propose the following diagram (Figure 1) to illustrate this development process.

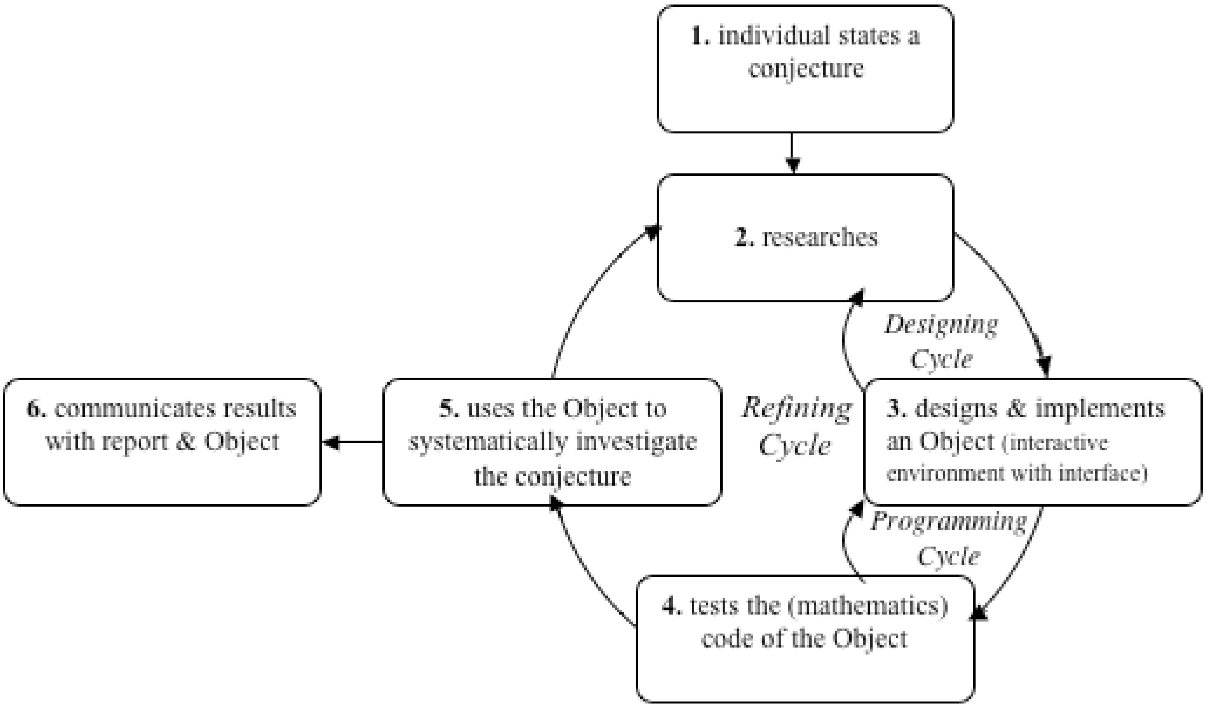

Figure 1. Development process of an Exploratory Object for the purpose of investigating a conjecture.

Here is a description of each step in the diagram.

1. Student states a conjecture, and may discuss it with the instructor; some of the more independent students wait until step 3 to discuss their project.

2. Student researches the conjecture using library and Internet resources, and may refine his/her conjecture. In conjunction with step 3, student identifies the mathematics, such as variables, parameters, etc., and is involved in a *Designing Cycle*.

3. With his/her understanding of the conjecture, student starts designing and implementing (i.e., coding) an interactive environment (i.e., program with interface) with a view to testing the conjecture. Student organizes the interface to make parameters accessible and to display diverse representations of results. As the interface plays such an important role in EO, we discuss it further in the next section.

4. Student selects, in a step-wise fashion, simple and more complex cases to test that the mathematics is correctly encoded and that the interface is fully functional. Together with step 3, the code testing and revising involve the student in a *Programming Cycle*.

5. At this step, student now returns to focus on his/her conjecture and uses the Object to systematically investigate it. Following the results of the investigation, the student may decide to refine the Object, e.g., introducing new parameters, etc., and be involved in *a Refining Cycle* (with steps 2, 3, and 4).

6. Student produces a report of his/her results and submits it with the Object. The report includes a statement of the conjecture, the mathematical background (from step 2), results of the exploration including an interpretation of the data and graphs (from step 5), a discussion, and a conclusion. This is somewhat similar to a science laboratory report. Building on this analogy, the Object is the laboratory itself. In other words, student submits his/her self-designed 'virtual laboratory' for the investigation of a self-stated conjecture together with his/her laboratory report.

Development Process of an Exploratory Object to Investigate a Real-World Situation

We propose the following diagram (Figure 2) to illustrate this development process.

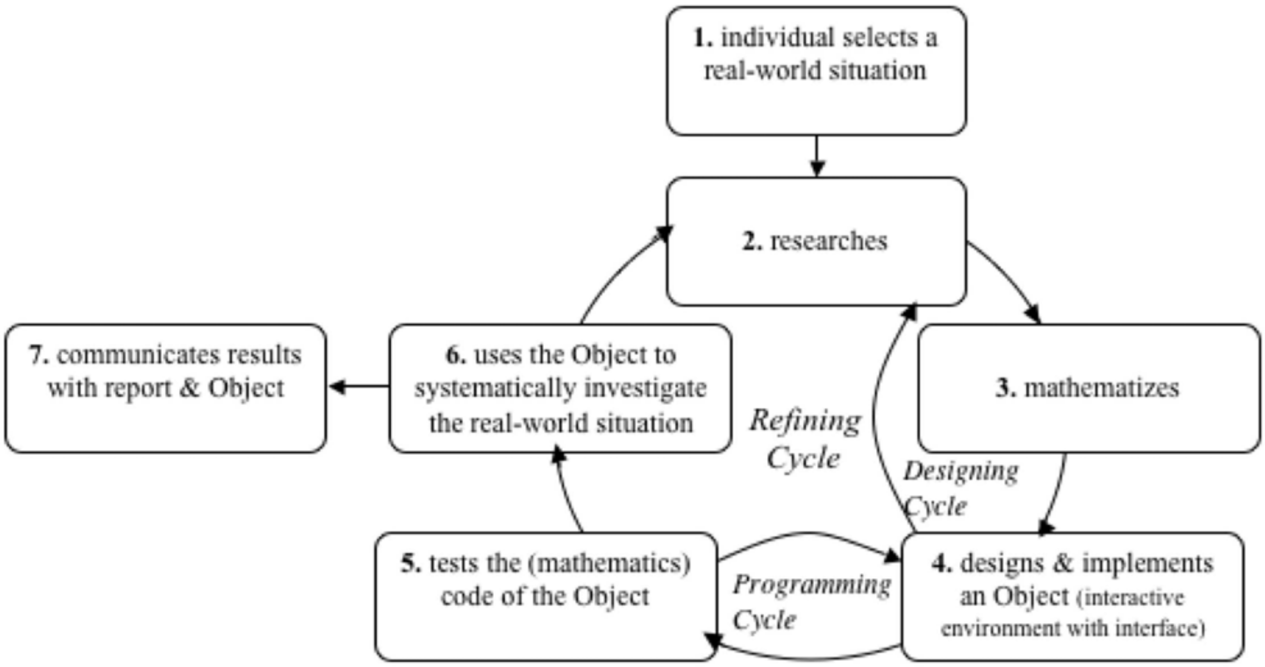

Figure 2: Development process of an Exploratory Object for the purpose of investigating a real-world situation.

Here is a description of each step in the diagram.

1. Student selects a real-world situation of particular interest, and may discuss it with the instructor; some of the more independent students wait to discuss their project until step 3 or 4.

2. Student researches the real-world situation using library and Internet resources, and may restrict or modify the scope of the real-world situation. In conjunction with steps 3 and 4, student identifies the mathematics, such as variables, parameters, etc., and is involved in a *Designing Cycle*.

3. Student develops a mathematical model of the real-world situation using the variables and parameters selected in step 2 and in the majority of cases, consults the instructor.

4. With his/her understanding of the model, student starts designing and implementing (i.e., coding) an interactive environment (i.e., program with interface) with a view to investigating the real-world situation. Student organizes the interface to make the model parameters accessible and to display diverse representations of solutions. As the interface plays such an important role in EO, we discuss it further in the next section.

5. Student selects, in a step-wise fashion, simple and more complex cases to test that the mathematical model is correctly encoded and that the interface is fully functional. Together with step 4, the code testing and revising involve the student in a *Programming Cycle*.

6. At this step, student now returns to focus on his/her real-world situation and uses the Object to systematically investigate it. Following the results of the investigation, the student may decide to refine the model and the Object, e.g., introducing or deleting, new parameters and variables, new conditions, etc., and may be involved in a *Refining Cycle* (with steps 2, 3, 4 and 5).

7. Student produces a report of his/her results and submits it with the Object. The report includes a description of the real-world situation, a development of the mathematical model (from step 3), results of the exploration (from step 6) including an interpretation of the data and graphs, a discussion, and a conclusion. This is somewhat similar to a science laboratory report. Building on this analogy, the Object is the laboratory itself. In other words, student submits his/her self-designed 'virtual laboratory' for the investigation of a self-selected real-world situation together with his/her laboratory report.

Development Process of a Learning Object of a Mathematical Concept

We propose the following diagram (Figure 3) to illustrate this development process.

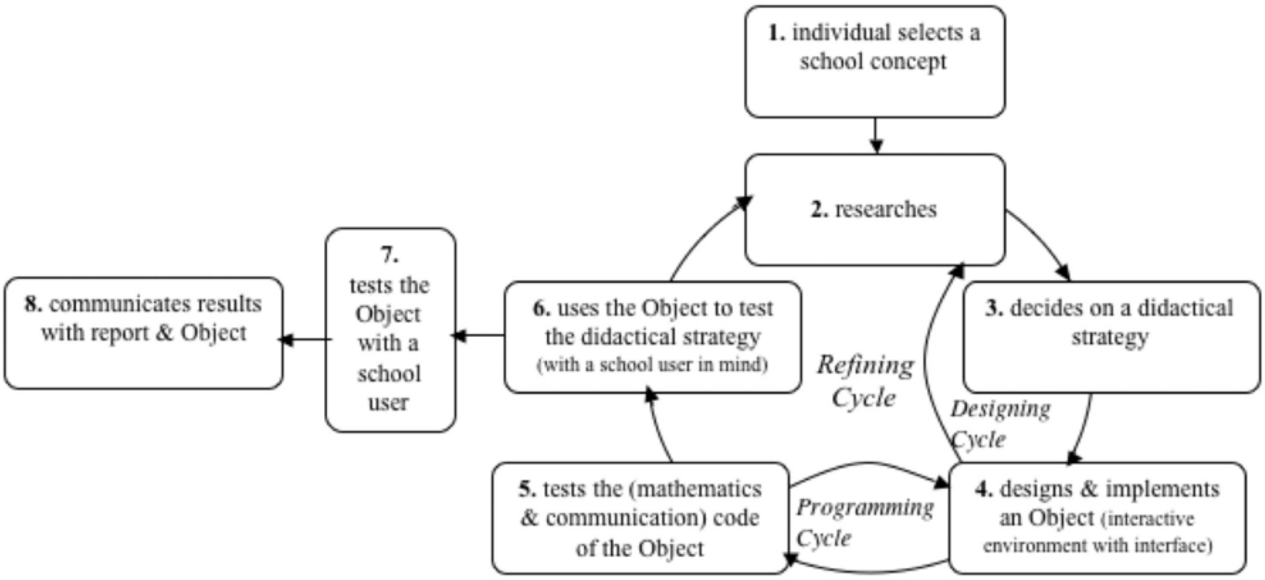

Figure 3: Development process of a Learning Object of a mathematical concept.

Here is a description of each step in the diagram.

1. Student selects a school concept.

2. Using library and Internet, student looks at resources about the concept and its teaching. In particular, student identifies when in the school curriculum the concept is taught, reviewed and expanded, what previous mathematical understanding, general knowledge and reading capabilities can be assumed, etc. In conjunction with steps 3 and 4, student identifies and develops the mathematics didactical features that could be used for his/her Object, and is involved in a *Designing Cycle*.

3. Based on the information gathered in step 2, student selects a didactical strategy for a fictive school pupil learning of the concept that may include developing a game or activity to engage the learner, breaking down the concept, setting up a testing procedure, etc. Student may discuss the strategy with the instructor or wait until the next step.

4. Student starts designing and implementing (i.e., coding) an interactive environment (i.e., program with interface) with a view to implement the didactical strategy. Student structures a self-contained interface realizing that the fictive school pupil will be using the LO independently. As the interface plays such an important role in LO, we discuss it further in the next section.

5. Student tests that the interface (communication, navigation, etc.) is fully functional and tests with simple and more complex cases that the mathematics is correctly encoded. Together with step 4, the code testing and revising involve the student in a *Programming Cycle*.

6. At this step, student now returns to focus on his/her didactical strategy and works through the Object with a school pupil in mind. Following the results of this investigation, the student may decide to refine the Object, e.g., changing the sequence of activities, improving the clarity of communication, etc., and may be involved in a *Refining Cycle* (with steps 3, 4, and 5).

7. Student tests his/her Object by observing a school pupil, at appropriate grade level, working with the Object. In some cases, student returns to the refining cycle and revises the Object.

8. Student produces a report of his/her results and submits it with the Object. The report includes the didactical purpose, the target audience, the mathematical background of the target audience, a brief account of the school pupil experience (step 7), and a discussion. This report is somewhat similar to a lesson plan, including a post-lesson reflection, though without a description of the lesson. Building on this analogy, the Object is the lesson itself. Thus, student submits his/her lesson plan of a self-selected mathematical concept in which the written description of the lesson is replaced by an 'interactive self-directed lesson (with a virtual learner)', i.e., by the Object.

ROLE OF THE INTERFACE IN THE DEVELOPMENT PROCESS OF EXPLORATORY AND LEARNING OBJECTS

The interface provides interactivity and (dynamic) visualization. In the Development Process of ELOs (Figures 1, 2, and 3), the student creates an interface in the Designing Cycle with the aim of using it for his/her mathematical or didactical investigation (step 5 in Figure 1 and step 6 in Figures 2 and 3).

During the Designing Cycle of an Exploratory Object, the potentiality of interactivity encourages the student to make explicit the parameters that could play a role in the investigation of his/her conjecture or real-world situation in such a way that they are accessible from the interface. The potentiality of visualization urges the student to decide on the representations to be displayed in his/her interface so as to best support his/her investigation.

At the step in the Development Process when the student uses the Object for his/her investigation (step 5 in Figure 1 and step 6 in Figure 2), both interactivity and visualization aspects of the interface play a role in the student's systematic investigation. The latter can be seen as a dialogue between the student and the computer, though the discussion is fully controlled by the student. During the systematic investigation, the student sets a question by fixing values to parameters (interactivity), the computer answers the question (visualization), and the dialogue continues in that way unless the student concludes that the answers are not satisfactory to meet his/her goal and decides to refine the Object (Refining Cycle). In other words, the student is in an *intelligent partnership* (Jones, 1996) with technology.

The interface plays a central role in Learning Objects but which is different than in the Exploratory Objects. A Learning Object is designed for other users to use by themselves, i.e., without the Object designer who is the student in our case. Thus the navigation in the interface should be very clear and easy. The interface should also provide, at any time, motivation for the intended users to go to a next step in the Object. As such, the visual presentation and the wording should be adapted to the intended users:

> For Learning Objects students [are] reminded constantly that they are designing interfaces for people who are not experts and that they need to take into account such issues as the user's age, educational level, gender, cultural background, experience with computers, motivation, disabilities, etc. (Muller et al., forthcoming, p.12)

Also, students should

> ... break away from the linearity of the written tradition in order to take full advantage of the technological paradigm. (Muller et al., forthcoming, p.12)

In step 8 of the Development Process of the LO (Figure 3), we introduced an analogy where the Object is a 'lesson with a virtual learner'. Using this analogy, the interface's potentiality of interactivity encourages the student during the Designing Cycle to develop an active 'lesson', i.e., a lesson that is interactive, with the intended fictive pupil. The interface's potentiality of visualization facilitates the development of transparent communication of the 'lesson' flow and makes it possible for the student to test his/her 'lesson' (steps 6 and 7 in Figure 3). In other words, we suggest that these two potentialities allow the student to develop a 'guided intelligent partnership' between a fictive pupil and technology.

REFLECTIONS

Diagrams shown in Figures 1, 2, and 3 clearly indicate our view that the student mathematics learning experience through the designing and implementing of an ELO is richer than what is experienced through activities of only programming mathematics. The interface plays a major role through its interactivity and visualization potentialities as it provides students with an opportunity to be involved in an 'intelligent or guided intelligent partnership' with the technology.

In a recent collaborative project between a local elementary school, *École Nouvel Horizon*, and our Department of Mathematics, MICA student Sarah Camilleri was involved as part of her Honour's project in the development of *Fractions Fantastiques/Fantasy Fractions* Learning Objects (Camilleri, 2007; Buteau et al., 2008a and b; MICA Student Project website, n.d.). In this development, she worked with a Grade 5 class, the teacher, and the school principal. It is worthwhile to explore the ways in which individuals took different roles and responsibilities in the Development Process (Figure 3).

Sarah and the teacher selected the fraction concept (step 1), and Sarah researched it (step 2). The teacher taught fractions to the class and presented the collaborative project. In the *Designing Cycle*, guided by the teacher and the principal, the Grade 5 pupils developed the dynamic mathematics lessons, interactive mathematics games, story line of the Object, its characters, etc., and provided drawings and written materials to communicate their ideas to Sarah who had to select and adapt some of them for programming purposes. The pupil design work was achieved in class discussions and in smaller groups of two or three. Within the *Programming Cycle* Sarah took the responsibility of faithfully implementing the pupils' design which also involved the digitizing of the pupils' drawings. The *Refining Cycle* involved Sarah and the teacher for testing the functionality of the Learning Object and checking the faithful integration of the pupils' ideas. *Fractions Fantastiques* Learning Object was presented by Sarah to the Grade 5 class and each pupil received a CD-ROM copy of *their* Learning Object (step 8).

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