Increasing opportunities for learning: Mobile graphing

David M. Kennedy
Department of Information and Applied Technology
Hong Kong Institute of Education

Douglas R. Vogel and Tomson Xu
Department of Information Systems
City University of Hong Kong

Considerable research has indicated the importance of having a sound pedagogical framework in place for the creation of learning objects which can support student learning, particularly higher order thinking skills. This paper describes the evolution of a learning object that has been in use for nearly eight years. The interactive graphing object (IGO) is a reusable learning object (RLO) that supports students to develop a deeper understanding of concepts that can be expressed graphically. Previous research indicated that the IGO facilitates higher levels of student engagement and deeper approaches to learning than more conventional static displays or animations of graphs. However, the student learning environment continues to evolve and diversify. There is a need for the development of RLOs that can keep pace with these changes. Some limitations with the original authoring environment which prevented more widespread use of the IGO have been addressed. Moreover, the advent of more powerful Personal Digital Assistants (PDAs) has resulted in the redesign of the student environment of the IGO, and development of a mobile form of the IGO—the mIGO. This paper discusses the design and development issues associated with improving a successful RLO, and then adapting it to facilitate learning in a mobile environment.

Key words: graphical knowledge, mobile learning tools, interactive graphing object, software design, meLearning, learning objects

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Introduction

The advent of the Web 10 years ago has resulted in radical changes in the manner in which both distance and face to face education is now delivered and structured. Concurrently, the evidence for validity of Moore's Law has been strengthened—that is, computing power has doubled every 18 months. The current power of the computer to store, manipulate, annotate and structure learning is profound, and the computing power of smaller and faster chips is now being used to create Personal Digital Assistants (PDAs) with features and facilities in the realm of science fiction just a few years ago. The student learning environment has moved steadily from the classroom and lecture halls to the Internet, and now the use of mobile technology is growing. In the Campus Computing Survey for 2003 the use of wireless LANS has grown to more than 75% of USA campuses. Students now have very high expectations that wireless will be available in all locations on a campus (Green, 2004). In Hong Kong the ownership of mobile devices has soared (including mobile phones); also, the spread of wireless networks on and off campus is also increasing rapidly, resulting in 110% mobile device penetration based on government statistics (The Office of the Telecommunications Authority of Hong Kong, 2004).

None of the growth in the power of computers or PDAs has negated the requirement to develop learning environments and learning tools that are pedagogically sound. Placing content on the web or storing it in a Learning Management System (LMS) is not sufficient for learning to occur (Ehrmann, 1995; Reeves, 2003; Rehak & Mason, 2003). There is still a need for learning tools that by design more readily support instructors in their quest to match the student learning outcomes with appropriate activities, assessment and feedback. Reusable learning objects (RLOs) may help to close the gap between what lecturers say they want as student learning outcomes and the mechanisms by which lecturers are currently able to provide feedback and support deeper approaches to learning (Biggs, 1989).

Graphs are widely used to explain relationships between variables and are often fundamental to the understanding of key concepts in science, business and medical sciences. It seems reasonable then to develop a RLO that enables students to articulate knowledge directly by sketching a graph onscreen rather than watching an animation or looking at a static image. The Interactive Graphing Object is an RLO that supports direct sketching of graphs on a computer and has stood the test of time. Originally the IGO was named the Interactive Graphing Tool (IGT) and developed to enable lecturers to develop questions (and provide feedback to students) that linked different representations of knowledge. The initial work focused on undergraduate chemistry for exemplars, but the IGO was suitable for any domain that had similar requirements. In chemistry the IGO was described thus:

> The interactive graphing tool (IGT) has been designed and used within a framework that links the literature on student learning to that on understanding symbolic representations of chemical phenomena. The IGT is an educational tool which is designed to actively engage students in constructing relationships between macroscopic properties of matter and the symbolic representations used by chemists to represent those processes.
>
> (Kennedy, Fritze & McTigue, 1997, p. 331)

In the initial design development phase it was realised that the IGT could be used in domains other than chemistry (e.g., physics, business, pharmacy and medicine). The range of curves recognised by the software algorithm is common to a variety of academic disciplines. Academic staff members from different faculties were interviewed during the design phase to ensure that the curves recognised by the software would satisfy (some of) the learning needs specific to the use of graphs in their discipline. For the remainder of the paper, the term IGO will be used to represent both iterations of the learning object.

Using a sound pedagogical approach

In thinking about the development of any reusable learning object (RLO), the designer needs to consider carefully how the student will actually use the tool. The IGO is has been designed to:

- actively engage the student in the construction of knowledge—the student must make a decision about what curve he or she will sketch in response to the question;
- support a wide variety of graph shapes (student input) and respond to less than perfect mouse movement;
- support an iterative approach to learning if sufficient feedback is provided by the lecturer in the design of the question;
- provide immediate multiple levels of feedback depending upon the match between student input and the correct answer; and
- provide a simple authoring environment for the lecturer to develop and publish questions.

(after Kennedy, McNaught & Fritze, 2004)

The last point above (ease of authoring) is crucial if the RLO is to be more widely adopted by lecturers. It has been one of the limitations of the original IGO preventing more widespread use, and a major reason driving the current project. This will be discussed in more detail in the next section.

The IGO has been designed from a constructivist perspective. It is intended to support higher order thinking and greater student activity than conventional static or animated versions of graphing tools available on the Internet (a search of Google will produce a large number of Java applets or Flash movies (.swf files) that create graphs or animations of graphs in a many subjects). When using the IGO a student has to make a significant number of decisions before sketching an answer. For example (depending upon the nature of the question):

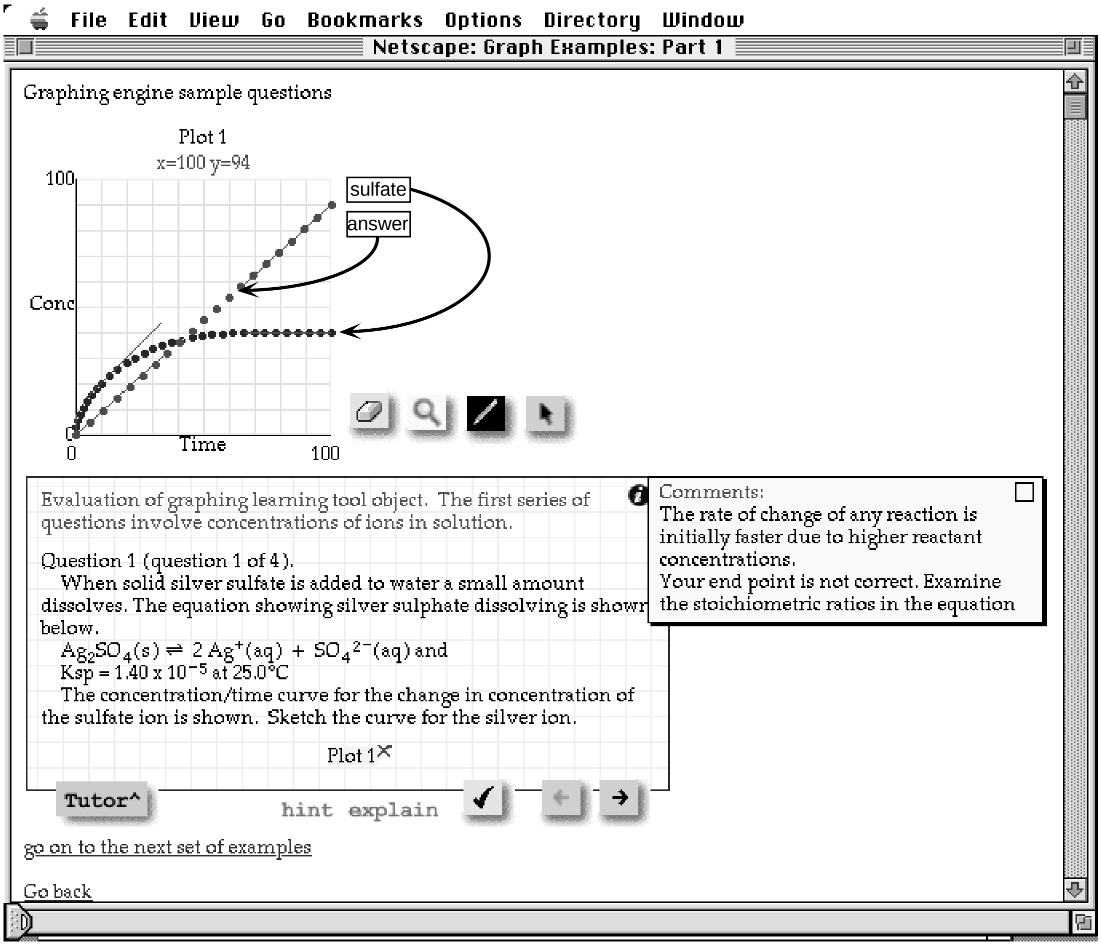
- Where does the graph start (is the start point known and/or significant)?
- Where does the graph finish (is the end point known and/or significant)?
- What is the general shape of the curve (e.g., exponential growth or decay, a hysteresis)?
- What is the start and end angle (is the change described by the question rapid or slow, does the rate change with time?)?

The above are key problems for students to solve. This is quite unlike selecting from a series of possible answers as in a multiple choice question, watching an animation, or inputting an equation and having the software draw the resultant graph. Formative evaluation with students at the time (1997) and after (2000) indicated the IGO was more challenging than conventional graphical questions as described above, (students found construction of knowledge more difficult) but ultimately more satisfying.

In summary, the IGO required students to sketch a graph directly on the screen with a mouse. The software algorithm was designed to respond to a wide range of common graph types including logarithmic, exponentials, curves, straight lines, and combinations of these curves. The second iteration of the IGT is the IGO, while the third (but closely connected) iteration is the Mobile Interactive Graphing Object (mIGO). The following section is provided to indicate the manner in which the IGO provided customised feedback to different student inputs.

Implementation dynamics

The IGO was developed in 1996 (Figure 1). The very favourable evaluations from students has encouraged the first author to continue development of the IGO (Kennedy, 2004).



Graphing engine sample questions

Evaluation of graphing learning tool object. The first series of questions involve concentrations of ions in solution.

Question 1 (question 1 of 4).

When solid silver sulfate is added to water a small amount dissolves. The equation showing silver sulphate dissolving is shown below.

$Ag_2SO_4(s) \rightleftharpoons 2\,Ag^+(aq) + SO_4^{2-}(aq)$ and

Ksp = 1.40 x 10^{-5} at 25.0°C

The concentration/time curve for the change in concentration of the sulfate ion is shown. Sketch the curve for the silver ion.

Plot 1

Comments: ☐

The rate of change of any reaction is initially faster due to higher reactant concentrations.

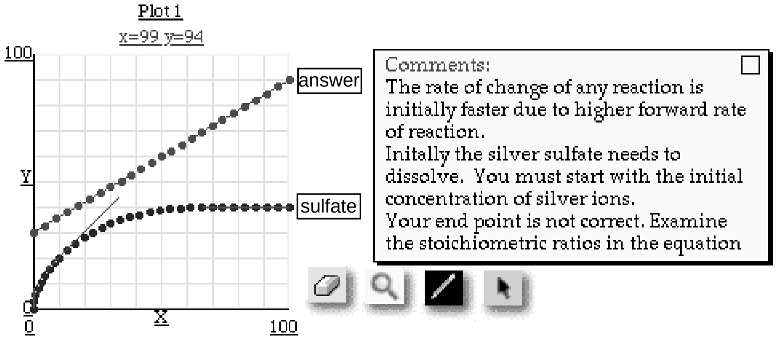
Your end point is not correct. Examine the stoichiometric ratios in the equation

Figure 1: Screen capture of the initial Interactive Graphing Tool (1997)

The original software was developed in Macromedia Director and implemented as a Shockwave object in a web page. Using the web environment enabled a wide variety of content (media) to be used in conjunction with questions. For example, lecturers could ask students to watch a video of a process and then estimate or describe the process graphically, effectively encouraging students to link macroscopic properties of matter with the symbolic representations—traditionally a difficult task. Figure 1 shows a version of the IGO with an example from chemistry. In Figure 1 the answer (the straight line) has resulted in two components of feedback related to the shape of the curve and the end point. The potential to provide multiple forms of feedback has been highlighted by students as a strength of the pedagogical design of the IGO.

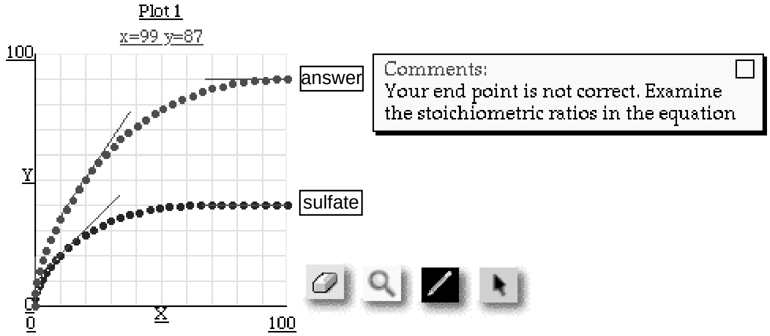
Two screen captures in Figure 2 show how the IGO provides multiple forms of feedback depending upon student input. In the first part of Figure 2 none of the student information is correct and there are three sentences providing feedback. In the second example only one sentence is needed to provide adequate feedback to the student. The message in the *Comments* (feedback) box has changed in response to the new input. Clearly, the quality of the feedback provided will be determined by the lecturer.

In this example the student has little knowledge of how the graphical relationship of the silver ion concentration changes. The feedback is detailed and addresses the start points, end points and the shape of the curve—all key factors in relating the process to the graphical representation.



Comments: ☐
The rate of change of any reaction is initially faster due to higher forward rate of reaction.
Initally the silver sulfate needs to dissolve. You must start with the initial concentration of silver ions.
Your end point is not correct. Examine the stoichiometric ratios in the equation

In this image the student answer has modified to include the correct start point and the shape of the graph. The feedback provided focuses on the importance of the end point for the graph—a key chemical concept.

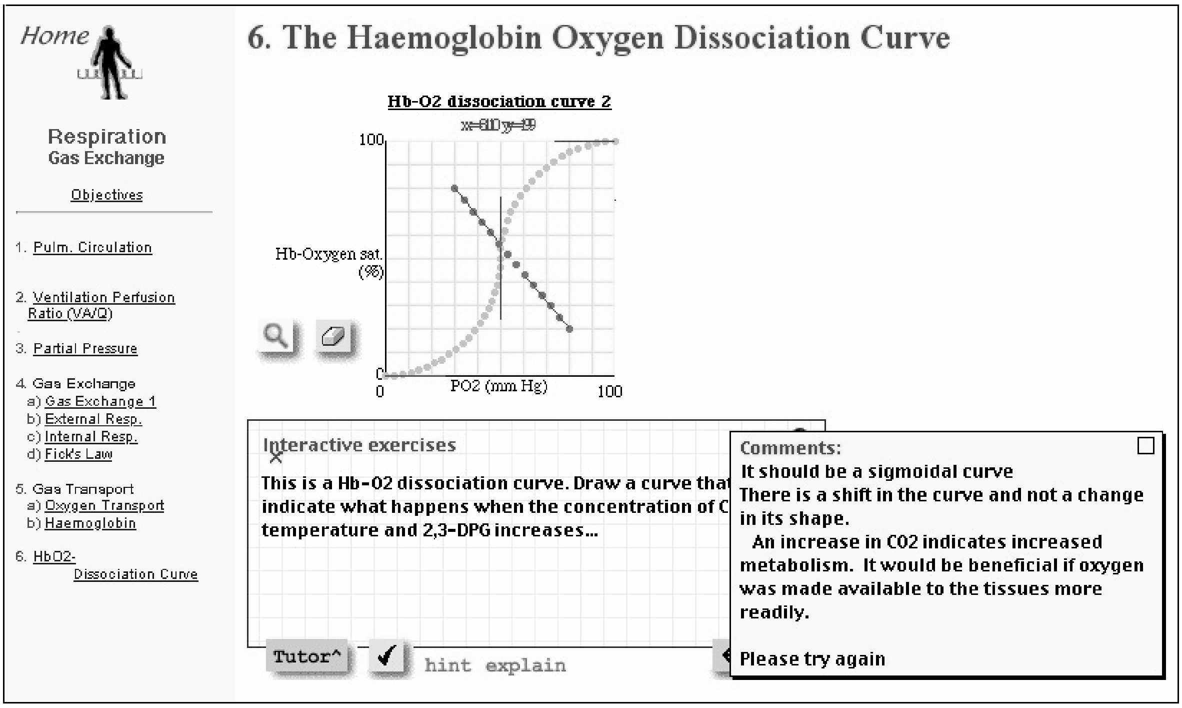


Comments: ☐
Your end point is not correct. Examine the stoichiometric ratios in the equation

Figure 2: Feedback of the IGO (1997)

The IGO is a stable tool and is still in use at The University of Melbourne without further significant development. Student evaluations of the IGO continue to be positive. For example, it has been integrated with several other online learning tools in a collaborative learning environment in physiology (Kemm *et al.*, 2000). Figure 3 provides a screen capture of the IGO in 2002. In 2003 funding was obtained from the LEARNet fund (Hong Kong University) for the redevelopment of the IGO. This provided the opportunity to develop a more robust, user friendly, authoring environment and extend the functionality of the new RLO. Figure 4 is a current version of the IGO (authoring mode).

The authoring environment is entirely forms based.. The curve parameters are set by sketching a shape with the mouse and then typing in the desired feedback. The authoring environment is complete. A number of changes were made to the interface after discussion with peers resulting in a more user friendly screen. The lecturer creates a question and then clicks, ‘Save’ (Figure 4). A file that encapsulates the entire question is created ready for upload to a web server for either the PDA or a web browser. There are still significant differences between the output for the web or the PDA. This is discussed in the next section.



6. The Haemoglobin Oxygen Dissociation Curve

This is a Hb-02 dissociation curve. Draw a curve that
indicate what happens when the concentration of C
temperature and 2,3-DPG increases...

It should be a sigmoidal curve
There is a shift in the curve and not a change in its shape.
An increase in C02 indicates increased metabolism. It would be beneficial if oxygen was made available to the tissues more readily.

Please try again

Figure 3: IGO as used in physiology collaborative learning environment (2002)

Issues and problems of wider use

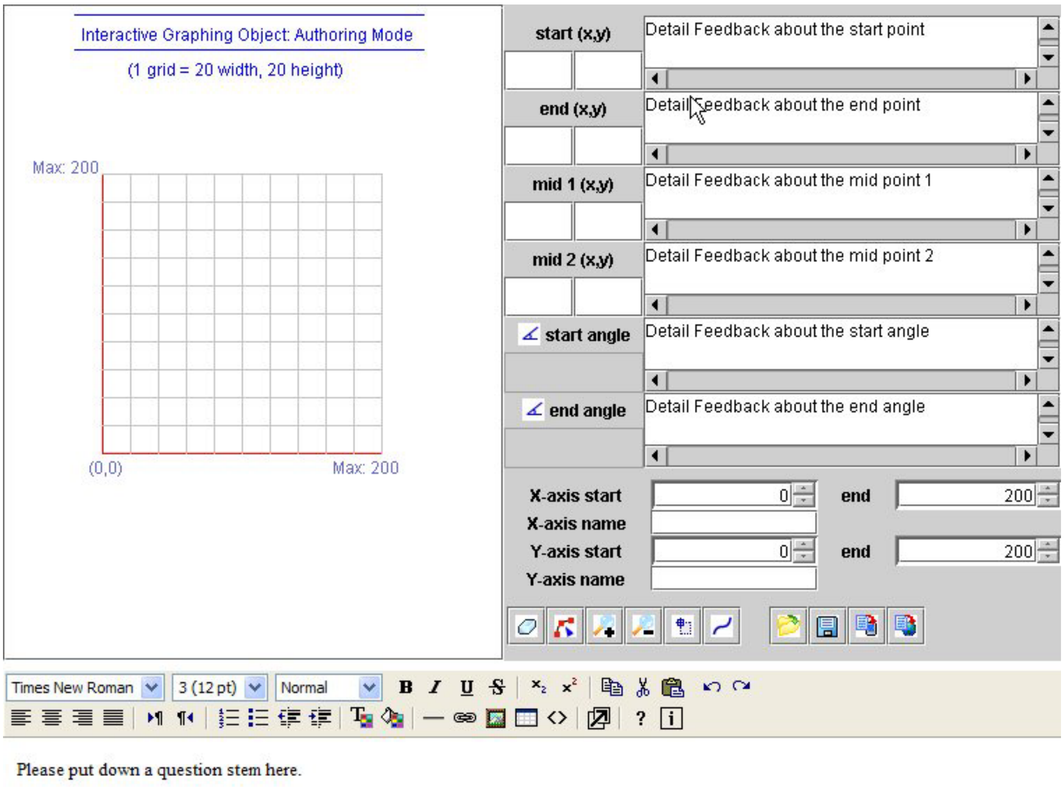
In the current developments the basic feature set of the original IGO has been retained. However, there were two significant issues that limited the more widespread use and dissemination of the IGO. One of the major issues associated with the original IGO was the software it was originally written in (Shockwave). Director has been subject to frequent changes and alterations to the Operating Systems (OS) of computers frequently resulted in the need for small but important adjustments to the code to account for the changes. Without such constant maintenance the original IGO would cease to function. This constant need to keep pace with upgrades in both Director and operating systems has been a strong negative in more widespread adoption. The second factor is authoring.

The IGO has been redeveloped in Java (a Java Applet) which enables a number of significant enhancements, particularly in regard to authoring. Java was selected as the programming language to undertake the redevelopment because it is:

- platform independent;
- more stable and subject to fewer changes than Macromedia’s Director; and
- a more powerful programming language than Lingo.

A key aspect of the new java version of the IGO is the ease of adjusting the curve so that both the qualitative aspects (general shape, start and finish gradients) and the quantitative aspects (start and end point) may be set. The IGO uses the mathematics of Bézier curves to fit a curve to the student input. A simple bézier curve is defined mathematically between two anchor points and the line between these two anchors is interpolated from dragging two control points or ‘handles’ attached to the anchors.

All curves drawn by the IGO, including logarithmic and exponential shapes can be simulated by a Bézier curve. In the current web version and the mIGO version the ‘handles’ of the Bézier curve can be shown by the lecturer and the student. This enables feedback provided by the lecturer to be more quantitatively based than previously possible.



start (x,y): Detail Feedback about the start point

end (x,y): Detail Feedback about the end point

mid 1 (x,y): Detail Feedback about the mid point 1

mid 2 (x,y): Detail Feedback about the mid point 2

start angle: Detail Feedback about the start angle

end angle: Detail Feedback about the end angle

X-axis start: 0 end: 200

X-axis name:

Y-axis start: 0 end: 200

Y-axis name:

Please put down a question stem here.

Figure 4: The IGO authoring mode (2004)

The changing educational environment: Get ready for meLearning

As electronic organisers become more powerful and wireless technologies more ubiquitous, it is reasonable to expect that both students and lecturers will take advantage of the opportunities to further customise individual learner experiences. The intersection of wireless and PDAs with real processing power offers an opportunity for mobile electronic learning, or meLearning. MeLearning has the potential to further customise and personalise the learning experience of students, hence the suggested name of ‘me’Learning, combining the personal experience with eLearning. Mobile devices are starting to become more important element in a learning environment that is independent of location and readily accessible.

Mobile devices currently have the power to run a large number of applications, especially those with task sharing options. However, there are considerable challenges associated with using mobile devices for learning. The current generation of mobile devices are still limited by several inhibiting factors that prevent people from initiating use of mobile devices or limit their current usability (Csete, Wong & Vogel, 2004). These include:

- Screen size is too small and limits information display. Colour depth and resolution restrictions cause graphic displays to be less presentable than that of a laptop screen (typically, 320x320 pixels).
- Data input on mobile devices is usually slow and inefficient.
- Connection speed is not yet fast enough to comfortably use many web or WAP access services.
- Applications do not run as smoothly as on a laptop computer because of the slow CPU and limited memory space.
- Battery life span is another concern as memory, CPU, display area, speaker and the antenna consume electricity quickly. Losing battery power can result in losing all data in some mobile devices.
- Ever changing OS (operating systems) of mobile devices complicate application selection and implementation.
- The current state of mobile infrastructure poses additional limitations and restrictions with no single standard or solution currently in the market.

From a learning perspective, these inhibiting factors stifle and dissuade learners from integrating mobile devices into their daily behaviour. But there is also reason to suggest that mobile devices be given a chance and current inhibiting factors be taken in context. Table 1 summarises the inhibitors of mobile devices, the effect on the development and deployment of the mIGO, and the corresponding solutions currently under development or envisioned within the short term.

Table 1: Inhibitors of mobile devices, current and forthcoming solutions
(after Csete *et al.*, 2004)

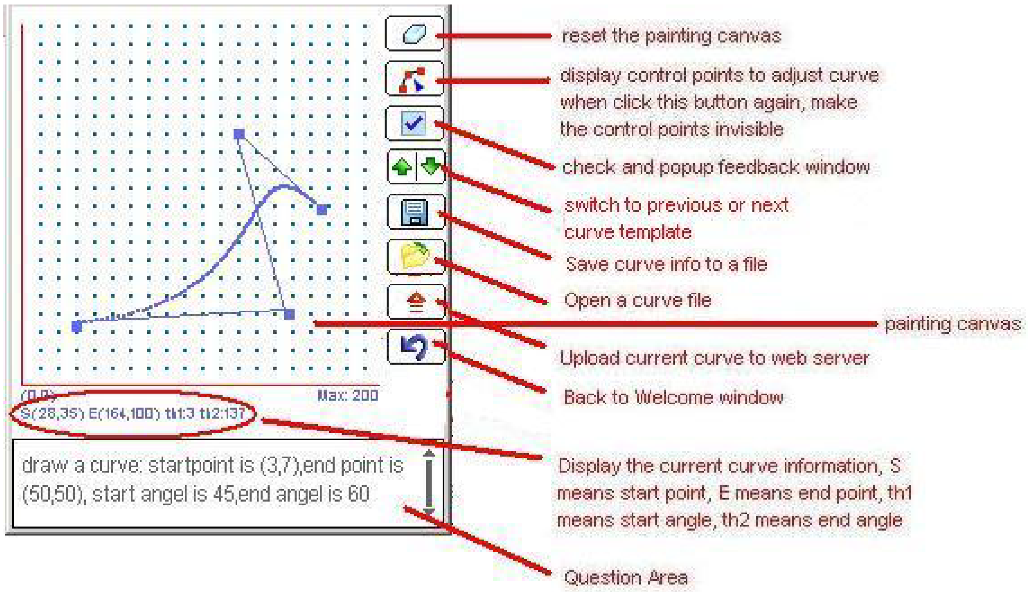
Inhibitors	**Relationship to current mIGO functionality**	**Future Solution**
Small screen size	✧ This is an issue and has resulted in the need to have an overlapping pop-up with the feedback to questions	✧ Flexible film display
Non-ergonomic input method	✧ The stylus is used for data input and is simple to use, and appropriate for the task required – sketching a graph	✧ Voice recognition ✧ Projection keyboard ✧ Cursive handwriting recognition
Slow CPU speed	✧ The mIGO is a small RLO and the speed of operation for curve fitting and feedback is acceptable.	✧ New breed of architecture for faster CPU
Limited memory	✧ The standard memory in most PDAs is more than sufficient to run the mIGO	✧ Expansion memory card ✧ Increase internal RAM capacity
Limited battery span	✧ This remains a issue for extended use	✧ New breed of lithium battery
Ever changing OS	✧ Currently, a proprietary system is used, however this could change with time and recent developments in open source solutions for the PDA	✧ Generic OS on PDA, mobile phone and smartphone
Infrastructure compatibility	✧ This is improving very rapidly. The plethora of wireless networks being created world wide has an astonishing rate of growth and PDAs are often equipped with more than one method of wireless connectivity	✧ Middleware to bridge the mobile and LAN platform
Connectivity bandwidth	✧ This is adequate for the mIGO, with bandwidth sufficient.	✧ 3G mobile capacity ✧ Bluetooth v.1.2

However, even if all of the technological inhibitors were to magically disappear, we must still recognise that mobile devices will continue to present application challenges as variety increases and trends towards ‘smaller and lighter’ sustain e.g., in ‘smart phones’, etc. Simply porting applications from traditional computing environments is not a viable solution either in the present or the future. Human computer interface and host coupling issues are particularly salient. The stylus driven interface of mobile devices and limited real estate encourage rethinking layouts to make maximal use of available screen space and device characteristics.

The current mIGO interface is illustrated in Figure 5. The degree of compaction becomes immediately apparent in comparison to the original and current web based IGO illustrated in Figures 1-4. As described in Figure 5, icons have been designed and clustered to support both and local and host connectivity functions.

Student feedback occurs in a pop-up window overlaying a portion of the painting canvas. Not withstanding the limitations of the mobile environment (Table 1) the mIGO functions very well, with curve matching and feedback presentation almost instantaneous. The stylus is also a very effective and appropriate input device for this type of RLO. The use of the curve handles allows a high degree of accurate placement of key curve parameters.

Beyond the human computer interface must be the consideration of host coupling and integration with base stations to effectively interact with mobile devices. As previously mentioned, development of a flexible capability for instructors to create applications with authoring mode support is an important consideration. As such, a host environment is created that enables material to be refreshed and made available to the students. Of concern is the degree to which the mobile devices operate independently and whether both uploading and downloading are supported to enable instructor monitoring. The limited capacity of mobile devices requires periodic connection to a host. However, the sometimes 'spotty' wireless connectivity domain encourages that mobile devices be able to work offline to enable maximal user independence.



draw a curve: startpoint is (3,7),end point is (50,50), start angel is 45,end angel is 60

reset the painting canvas

display control points to adjust curve when click this button again, make the control points invisible

check and popup feedback window

switch to previous or next curve template

Save curve info to a file

Open a curve file

painting canvas

Upload current curve to web server

Back to Welcome window

Display the current curve information, S means start point, E means end point, th1 means start angle, th2 means end angle

Question Area

Figure 5: The mIGO (2004)

In its current implementation, the mIGO downloads a limited set of questions and responses to enable the students to work offline, store results locally and re-connect to the base station only when new questions are desired. Although the focus is on formative learning use by the student, the capability also exists for results to be uploaded to the host.

Discussion

The ubiquitous nature of mobile devices signals a new area of pedagogically driven applications. Beyond the technologically driven solutions to current inhibiting factors in mobile devices lies a range of opportunities that encourage ingrained learner use. Development of an application portfolio and associated support for integration into varied education and learning activities in and out of the classroom can easily be envisioned. However ubiquitous computing does not necessarily lead to ubiquitous learning. The challenge is to efficiently develop a continually refreshed set of applications that are genuinely useful and accessible. Our students increasingly expect more and are less inclined to be tied down to fixed computing resources. Mobile devices provide degrees of freedom but introduce additional complexities in creating a learning environment in which computing support is part of the extended environment in which the students exist, both academically and socially.

A broad range of staff development issues and challenges exist to assure that the applications are appropriately integrated into course activities and curricula and generally encourage extended student use. Some instructors are naturally drawn into trying new approaches to learning. Unfortunately, many are not and remain especially apprehensive about new technologies that might require large amounts of effort or upset established ways of course conduct. Professional support as well as collaboration among instructors is required to create a critical mass and expand acceptance. Encourage for sharing and creating repositories of learning objects becomes paramount to expanded application. This requires a cultural shift as instructors have to think beyond their immediate domain to creating learning objects that don't become shelf ware or their own personal closely held bit of support. Management sensitivity to providing incentives and support needs to be initiated.

From an institutional perspective, a variety of readiness and integration issues need to be addressed to minimise barriers to use and help assure program success. Having a portfolio of both administrative and coursework applications that support a wide range of student needs and interests running on a mobile device helps ensure sustained use. Institutional portals need to be mobile sensitive in facilitating access and providing compatible support. For example, web page content needs to be formatted such that it can be reasonably viewed on mobile devices. This is not a problem, as can readily be seen by looking at news sites (e.g., http://www.cnn.com), but does require consideration and layout attention on the host site. This often entails expanded consideration of website objectives, requirements and delivery modes. Additional attention needs also to be given to telecommunications infrastructure to assure reliable access to institutional resources with sufficient bandwidth to avoid frustrating mobile device users.

Summary

We feel that creative use of emerging mobile devices coupled with sound pedagogically driven applications provide an opportunity to extend traditional teaching and create learning environments that will be well received by students. Properly applied, these devices extend instructional and institutional support capability by putting resources directly in the hands of the students. The functioning mIGO has demonstrated that the current state of development of the PDAs provides sufficient processing power and screen real estate to warrant further development and evaluation, providing opportunities for lecturers to develop learning environments that are more personalised and engage students more actively. The mIGO application presented in this paper is representative of an extended learning opportunity. In using the mIGO, lecturers may customise feedback to be as complete or as minimal as desired. Therefore, the quality of the feedback students receive remains where it has been—firmly in the hands of the teacher. There are, however, many issues that need to be addressed on technological, course, faculty and institutional levels for these opportunities to become universally successful and sustainable. Activities, courses and curricula need to be designed that synergistically incorporate technological opportunities. Pedagogically defined requirements need to drive technology and application development. Faculty development and institutional support needs to be provided that enables learning on all levels in an integrated fashion with special attention to quality of life. Overall, the future is challenging but bright.

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David M. Kennedy, Department of Information & Applied Technology. Hong Kong Institute of Education, Hong Kong. kennedy@ied.edu.hk
Douglas R. Vogel & Tomson Xu, Department of Information Systems, City University of Hong Kong, Hong Kong. isdoug@cityu.edu.hk and tomsonxu@cityu.edu.hk

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