Challenges and choices in developing complete digital courses in upper secondary Mathematics education

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Abstract

The University of Agder (Norway) is developing internet-based learning resources in mathematics and physics at high school level in an ongoing project, parAbel. This is done because of failing interest and recruitment to university studies of mathematics, science and technology, and the need of teachers and learners for ICT-based resources. The intention is to develop a free and online national learning tool for the entire curriculum of mathematics and physics in high school. The project aims to have a high ratio of visualisation and multimedia learning objects. The key factors for success are considered to be the development of multimedia learning objects in large number and quality, to balance text and learning objects and to activate the students as much as possible by interactive design. This paper presents experiential insights from the development field. It outlines the present version of the mathematics part of the resource, a comprehensive course providing the central elements of the subject in the Norwegian curriculum at upper secondary level, and discusses issues relevant to authors and programmers when developing multimedia learning objects.

1. Introduction

There is a need for more students choosing further studies in mathematics and physics in upper secondary school as well as better recruitment to scientific and technological programmes in higher education in Norway. Practical work and the use of ICT are among the strategies to achieve this (KD, 2006). Teachers in Norway are looking for ways to use ICT resources to support their teaching and their students' learning of mathematics. In some upper secondary schools in Norway all students have got laptops and work computer-based. Besides, a large number of people attempt to study mathematics independently outside the classroom, e.g. adults in working situations, in sparsely populated regions or during military service. They need some ICT-based resources they can engage with.

The project ’parAbel’ is aimed at developing online resources in mathematics and physics for upper secondary school. Core elements in the resources (parAbel, 2007) are learning objects, entities which can be used, re-used or referenced during technology supported learning (IEEE, 2006). The project started in 2003 and is currently financed by the Norwegian Directorate for Education and Training and the University of Agder. It is supported by subject specialists of the Norwegian Centre for Mathematics Education and the Norwegian Centre for Science Education.

The resources in mathematics are intended to cover all mathematics curricula qualifying candidates for higher education, and to support teaching and learning throughout the subject curricula in mathematics. They are intended to be used in a wide context; not to compete with textbooks or interactive software as Cabri, GeoGebra or Derive.

The paper will first present the current version of the mathematics courses and next discuss the development team’s underlying theoretical positions. Then it will discuss some issues and challenges considering how to serve different groups of learners and how to provide dynamic and highly interactive resources. Examples of choices will be given.

2. What parAbel is

Both online programs in mathematics and physics respectively, follow the curriculum, the objectives of the subjects, their main subject areas and competency goals. The mathematics resources, which this paper focuses on, will to a great extent cover the whole syllabus for the year-long courses Vg1T (numbers and algebra, geometry, probability, functions), R1 (geometry, algebra, combinatorics and probability, functions) and R2 (geometry, algebra, functions, differential equations). It has been updated to respond to a new national curriculum that was introduced in 2006-2008.

The approach sets out from the mathematics that is intended to be learned, rather than learner characteristics. The aim is to present the mathematics in a logical and accessible fashion. The resource supplements the regular textbooks and promotes the subject in different and interactive ways, e.g. by providing step-by-step instructions, formative assessment exercises, learning objects and animations that provide links to real life. Each parAbel course is organised as an interactive book with chapters and sections and related to a subject curriculum. The learner may address any subject from a graphical menu, a folder menu or turn the pages. Sections are compounded with theory and examples, as well as small exercises and simulations as the learner progresses. The last sections in each chapter are extension exercises and summary. In addition, there is a glossary and an advanced graphic calculator.

The material is provided in a LMS [Learning Management System][1] that has an integrated system for administration and reporting course progression. It supports user-to-user communication by, e.g., providing chat, discussion forum, video conference and file sharing. The LMS is fully SCORM/AICC compatible, and integration to the schools' own LMS is non-problematic. That opens for direct linking to each unit in parAbel, e.g. a single learning object, section or chapter, and for incorporating links into the total educational material shared with the students. Schools without LMS and private individuals have to login to parAbel.

The product that the project is sharing is in the process of development, it is not a completed, fully tested and evaluated product. The number of upper secondary schools in Norway registered as parAbel-users has been increasing from about 30 % in 2005 to more than 50 % in 2008.

3. The developers' approach

The development team involves participants with different backgrounds. The core authors are mathematicians and physicists, subject specialists with substantial classroom experience, and technical advisers and Flash-programmers. Members of the course author team for the Mathematics courses have backgrounds as mathematicians and experienced educators. They are well-versed in selecting topics that are relevant to students' needs and can argue for the mathematical quality of what is been developed. At all times there is at least one author with Flash[2] competency in the team who is able to argue for the technical feasibility of ideas and functional specifications chosen, and to a certain extent able to carry out some programming with this authoring software (Fig.1).

[1] MentorKIT is LMS authoring software produced by Norsk Interaktiv AS. Møllergata 4, 0179 Oslo. Norway.
[2] Adobe® Flash® is authoring software for creating digital animations and interactive content.

3.1 The constructivist principle

The project takes the perspective of an open experiential pedagogy, based upon a theoretical position in cognitive and social constructivist thinking and the pedagogical tradition of the Nordic countries (e.g. the intention of inclusiveness, learner empowerment, democracy etc.), while embracing new possibilities for making subjects attractive and engaging.

When espousing social constructivist learning theory, the developers are aware that one common objection is that the e-learning object hampers social interaction. Answers to this criticism run along at least two lines of reasoning. The first is the needs of isolated learners. This will be dealt with separately. With the presence of a teacher, there is a different set of challenges. The implementation in any classroom will vary with the manner in which the teacher uses the resources, and the types of tasks and targets the teacher sets. When teachers are going to bring these resources into the classroom, they need to work through the units first, then think very carefully about how the resources can be implemented in a productive learning environment to communicate mathematics in an investigative and inquiry oriented style. This is the teachers' responsibility.

The authors in the development team are mathematicians being aware of the epistemological claim of constructivists that knowledge in the learners heads, “in-here”, is both separate from and an objective representation of a reality, “out-there”. They are trying to develop learning objects realising aspects of what is out-there. Mathematicians know what a function is, in the same sense that they know what a car is. The function becomes in a sense a learning object or the substance of a digital learning object which the mathematician wants to design in a way that helps students to develop their own function concept. Then the development team creates learning objects, to motivate engagement, activity and reflection. This is what the constructivist view of learning is drawing attention to: Learner activity, learner motivation, learner engagement and the sustained engagement in learning activity that is actually going to produce an enthusiasm to continue.

3.2 Working practice

At the start of a project year, the author team sets apart time for brainstorming. The starting point is the mathematics curriculum and the learning objectives. The team discusses how each mathematical idea can be represented, what will be suitable to visualize, and which kind of interactivity would support learner's exploration. Some ideas are based upon team members’ knowledge of mathematics and experience as mathematics educators. Some ideas arise from the study of the literature for mathematics teachers, articles which teachers might have come across. Some ideas build upon what is recognized as being of value elsewhere, e.g. some ideas have emerged from studying the material of the Freudenthal Institute (WisWeb, 2004). Other ideas are conceived by the authors in a symbiotic activity related to research in the field of learning objects. They are frequently evaluating mathematical learning objects at several levels of the educational system. This is done according to taxonomy, being in progress and aiming to cover mathematical, pedagogical and didactical reasoning.

All ideas are collected and discussed in order to estimate their value for teacher and learner. The activities and their risk for development (time, cost, and functionality) are sorted by their value and risk. The objects with high risk and high value are to be started first, second the objects with low risk and high value, and finally the objects with low value and low risk. The author team then works out a short synopsis, in some cases a broader functional specification.

These descriptions are then ready for the programmer and the cycle of programming and testing, which is preferably done in close collaboration between authors and programmer.

Because of the budget limits the project engages low cost Flash expertise such as university teachers, multimedia students and expertise from the low cost market. This expertise is especially necessary in order to develop scenarios and learner activities from scratch, complex animations and advanced interactivity. Despite limited access to programmers, the project aims to make such learning objects the core attractions of parAbel and uses much energy and effort to provide a rich variety of unique learning objects.

3.3 Example

An example will take you from how an idea was worked out, specified and brought to realization. The author team wanted to visualize the sine function by a real life graphic and phenomena well known to Norwegian students. It was decided to lean on a discussion in a Norwegian journal for mathematics education. The question was if the curve drawn by the sun at midsummer north of the Arctic Circle within 24 hours could be described by the graph of a sine function. Statistical data were provided. The team then worked on the specification of a learning object, particularly requiring how the learner might observe the path of the sun and how the application will respond to the learner. It was agreed to have 4 stages: Stage 1 presents a photo collage that assembled 24 vertical strips of photographs of the sun in correct positions and with changing sun height over time and provoke the students' imagination. Stage 2 animates the sun's movement faithful to real data. Stage 3 shows the sun's path continuously being traced, before a curve is being overdrawn. Stage 4 provides a function plotter for sine curves with one slider for each parameter, as well as an assignment asking the student to inquire whether the sun's path can be modelled by a sine curve. Choices were made, arguing for the mathematical quality and for how to make the learning object attractive and interactive in an engaging way, within the range of what is possible to accomplish. Later re-development cycle in collaboration with authors and programmer will follow.

The ideal use of the learning object "The path of the sun" will be in a context where students can talk together, where they can use some time to experience and discuss aspects on the sine function concept, as how changing the function's parameters effects the sine graph. It would help to have a teacher to consult when trying to get to their own understanding.

4. Challenges and choices

4.1 Serving different types of learners

Here I briefly return to the challenge with the lone learners. Especially with the lone learners, the challenge is how to compensate as much as possible for the lack of support from a teacher and fellow students. Good teachers would carefully prepare for demonstration and dialogue with the students. They would want to make the students conscious, think about or reflect, and ask questions.

Multimedia and dynamic presentation can to some extent mimic what a teacher might do in class, by breaking the topic down into manageable pieces with questions asked as the teaching progresses, and theory presented and explained. The student is free to demand the presentation step by step or in greater units, and free to work on the material for as long as necessary. In presentations, graphical animations come to their own, for instance visualizing the development of a formula, demonstrating how to construct a hexagon or relating algebraic theorems to geometry. The presentations of theory will not all be equally important for in-classroom learners, but they could very well be helpful for revision or recapitulation.

To support the learner studying alone, the project aimed to provide a high ratio of self-assessment exercises intended to challenge the learner's beliefs and knowledge. Especially for certain problems in calculus and where procedures are to be learned, multi-step interactive explanations or exercises are given. They let the learner make decisions and follow up their choices with links, hints and examples. The ability to ask the learner non-trivial questions and give non-trivial choices, to reveal misconceptions or intercept mistakes often made, is based upon the knowledge and the experience of the authors as mathematics teachers.

Learners in distributed or blended learning situations are in a position between the in-classroom learners and solitary learners. Effective blended teaching depends on appropriate opportunities for dialogue and on appropriately structured learning materials (Moore and Kearsley, 1996). While initiating person-to-person interaction in classroom sessions or in the LMS must be the responsibility of their teacher, the developing of interactive content and to engage the learners is the authors' responsibility.

4.2 Extending interactivity

Rich and complex interactive learning objects are slow to develop, and the Flash programmers available will be kept busy in the production of a limited number within the resources and time-scale permitted. The project group found a balance by developing a certain number of one-of-a-kind learning objects, using built-in learning templates in the LMS and learning interactions in Flash, and developing user-made Flash templates. Overall, it helped to a great extent to provide a high proportion of interactivity.

The various one-of-a-kind learning objects developed for parAbel offer content dialogue and content-interaction on the learner's initiative in many different ways. The theory parts of the chapters are built on user-made Flash templates, making explanations interactive and revealed by student demand. The majority of formative self-assessing exercises with the purpose of keeping the learners active and to let them check if they did pick up the main concept, could be rather simplistic. Thus they are mainly built on templates, while a small number are developed as one-of-a-kind artefacts. Concern for quantity and developmental effort was important motives for using built-in templates[3]. They also enable all authors to participate in the design. The authors' creativity to find effective, challenging, provocative questions and answers will be the most important factor in whether these formative assessments objects will achieve their goal.

Promoting deeper learning would demand more pedagogical interactivity. Some efforts are made. Authors and Flash-programmers collaborated closely on Flash templates for activities that could be re-used. Among others, they served these purposes: Firstly, providing hints on demand; for instance an agent, the "Oracle", was developed to give a series of prepared hints when consulted by the learner. Secondly, providing feedback, scoring and tracking in a way that, giving points for the grade of performance, will reward the learner for redoing and improving, and thirdly, to let the learners choose the degree of difficulty. Finally it helped cut

[3] Templates in use are e.g. Multiple Choice, Write correct answer, number or formula, Complete table, Click on correct hotspot to continue, Drag text to correct hotspot of graphics, Match sentences or words, Drag text in correct order and games like Betting with one or two players.

down the development time required for the programmers, as they could re-use components and the basic structure from one unit to the other.

The first parAbel generation in 2003 clearly had a predominance of text and static graphics. The 2007 version supports user activity on screen in every part of the mathematics course, both in the presentation of a specific topic, in formative assignments and tasks, and in assessments. The non-static content had increased considerably, from 5 %[4] to 88 %[5]. This section has referred decisions that helped to provide a high proportion of interactivity throughout.

5. Further work

With several years experience, parAbel is still an ongoing project. There will always be a potential to improve the quality and to make the resources richer. The parAbel team is continuously working to advance the product. There is a new release at the beginning of each school year that implements recent developments.

By now parAbel provides 3 different courses in mathematics. The material is approved by an academic review team for its mathematical quality and coverage of the Mathematics curriculum. But it is as yet not fully completed, tested and independently evaluated.

The development team listens to the teachers and individual learners. Teachers report on the benefit in terms of using the software or parts of it in their classroom. Some learners give feedback on how the material may benefit their understanding of a subject matter's concepts or principles, but for the most part they give expression of appreciating the motivational, interactive and visual qualities of both instructions and learning objects. The development team wants to have a better source of information and feedback that might tell them how effectively the product is being used. This is about formative evaluation of a product which is large, diverse, used widely, and in many different ways. It will be an extensive work to do.

No formal pedagogical or mathematical didactical analysis has yet been done where the focus comes from the perspective of the learners rather than from the perspective of the mathematics. There have been attempts to have a formal evaluation, but this is made difficult by the quick pace of change. The project experienced this as a more fundamental problem related to the quick turnover of digital artefacts. As for now, it do not have a clear strategy on how to meet this challenge, but post this as an area for future work.

It is worth considering forcing the LMS development towards Web 2.0 features with community-generated tag databases, where teachers and learners give feedback to learning objects, providing information to development and research.

Hopefully the discussion of learning object examples following my paper will charge the resource development team with new ideas for what parAbel can do better. Mathematical didactics experts are welcome to join and inform the project group what is happening with the learners and their teachers when exploring the learning resources. Their aspects of epistemology could bring more "understanding of the learner" into the project.

At the current time, new challenges and possibilities are arising when trying to achieve new mathematical learning objects, especially games, developed with the help of partners in

[4] The approximate ratio measured in screen space was 70% text, 25% pictures and 5% animations [Aas 2005].
[5] The ratio of 88% non-static content is extrapolated and based on a sample of 25 % of the R1course materials.

China. The challenges are in the communication on mathematical, pedagogical, didactical and technical perspectives and the ordering and developing in collaboration.

Provided that durable financing is found, the project has the goal of developing one new Maths course a year and improving the current ones. While the more theoretically oriented subject curricula have been covered, teachers are requesting equivalent resources for the more practically oriented variants of subject curricula in mathematics that also qualify candidates for higher education. This indicates that there is more work to be done in future.

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Fruitful discussions about central aspects of parAbel with assistant professor Heidi Oftedahl, University of Agder.

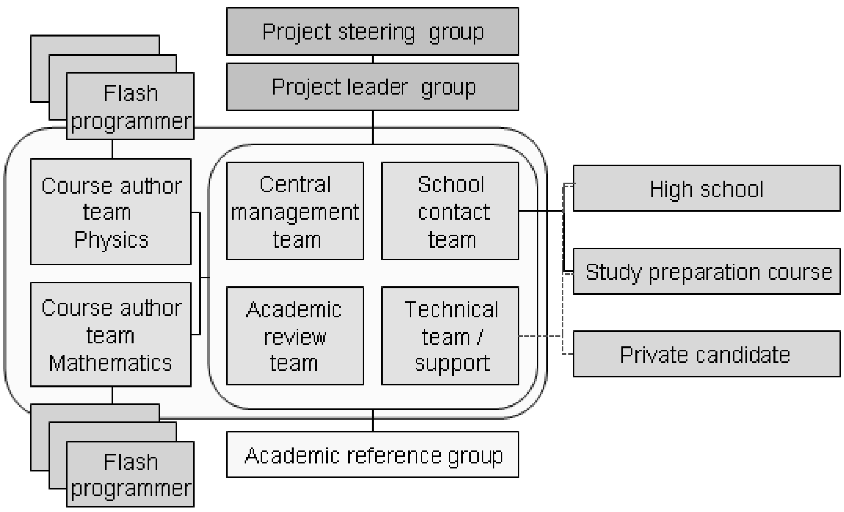

Fig.1: The project's development and administration model