

Development of the Virtual Learning Environment for the Differentiated Instruction of Mathematics in the Comprehensive School

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Abstract. During the last few years the Finnish students' skills in mathematics have been declining, and the teachers have utilized the information and communication technology a little. In addition, the reform of the strategy of special education in comprehensive school in Finland in 2007 has increased the need for differentiated instruction. Scientifically, it is interesting, whether information technology (IT) could help to differentiate instruction and could IT offer opportunities not yet tested in practice. We therefore ask: Can we build the IT-system, which allows to differentiate instruction in mathematics in comprehensive schools? In this article, we describe such kind of the virtual learning environment. We used action research in the development and we describe the development process, which has lasted seven years, this far. The built IT artifact seems to satisfy the requirements of differentiated instruction. Teachers now use the system consistently, and it demonstrates that we found a successful solution to our problem. We present principles to construct a learning environment for differentiated instruction.

Keywords: differentiated instruction, mathematics, virtual learning environment

1 Introduction

We study the differentiated instruction (DI) of the mathematics of the higher classes of the Finnish comprehensive school with the help of information technology and communication technique. Finland's excellent results in the PISA studies have been declining [1], in national studies the learning results have also been declining [2,3] and in the utilising of the information technology in the teaching, the Finns have regressed measuring internationally. Especially the teachers of the mathematics have utilised little information technology [4]. Based on these facts and based on the subjective development needs of the teaching I and my colleague Sauli Hartikainen began to develop a virtual learning environment for the teaching of the mathematics in 2006. The Ministry of Education renewed the strategy of the special education in comprehensive school in 2007 [5]. The reform was executed as a change of the law in 2010 [6], which increased the need for the differentiating of the instruction further. In

this strategy, all the pupils belong to the group of the general teaching. This form of the integration is called inclusion. The principle of the inclusion is that all the pupils go to school together, the common teaching for the pupils has been arranged according to individual preconditions and every pupil and member of the staff knows that he is accepted and appreciated in the school community [5]. The differentiated instruction (DI) is needed to carry out inclusion. DI is defined as a process, where the potential and the abilities of the different pupils are made to get out and to develop in the same class without compelling the pupils to adapt to a curriculum [7, 8]. According to Tomlinson [9], there is a question about both of the teaching philosophy and of the ordinary methods in the differentiated instruction.

Rock et al. [10] and McQuarrie et al. [11] stated that the pupils, who had suffered from the learning difficulties, benefited more from the differentiating instruction than the pupils who usually got through. Tieso [12] has noticed that the differentiated instruction has offered challenges, which promoted the learning of the gifted pupils in the lessons of the mathematics. Differentiated instruction, which enabled the pupils to proceed on their own tempo and where the pupils got regular estimates from their working, led to the bigger effectiveness [13]. The self-assessment and the supporting the own responsibility were considered important. Tomlinson et al. [14] have noticed that the differentiating of the instruction is scattered and random in practice even though the teachers want to do it. Li and Ma [15] have perceived in their meta-study that in the use of the computers in the teaching of the mathematics there have been obtained better learning results than without the computers. The systematic literature review without gaps has not yet been performed but according to the wide review that has been executed the similar study has not been found.

A need for the differentiated instruction of the mathematics appears in practice. The scientific study has been minor from the differentiated instruction of the mathematics utilising information technology. We ask for the previous: "Can we build the IT-system, which allows the differentiated instruction in mathematics in comprehensive schools?" The sub questions in detail are: "Does the information technology promote differentiation? Can instruction be differentiated with the help of the information technology in the way which has not been tried earlier? "

The objective has been to develop the artifact to solve the practical problem. We therefore examine the research problem from the frame of reference, which has been created by March and Smith [16] and developed by Hevner et al. [17]. In the frame of reference, there are two halves: solving of the practical problem and evaluation of the implementation. Vaishnavi and Kuechler have gone on the thinking of the problem of the design science research (DSR) in the Internet [18]. Peffers et al. [19] state that the development of the design science research as a method of the IT study is minor. According to them, the numerous studies have been carried out from the point of view of the design science research without realising. Järvinen [20] compresses the researcher's action to solve the practical problem and to get scientifically interesting information. The action research is this kind of research method, which is very much similar to design science research [21]. We use a canonical action research [22] for the description of the developing of the artifact where diagnosing, action planning,

action taking, evaluating and specifying learning are repeated as several loops according to a cyclic process defined by Susman and Evered [23].

We have adapted Mathiassenin et al. [24] recommendation in the reporting of the action research. The research place and the study environment are described in the second section. In the third section, the long study process is described cycle by cycle. The description has been presented at a rather abstract level for the sake of the limited length of the article. The fourth section contains the lessons learned during the process. In the fifth section it is shown that the artifact fulfills the demands of the differentiation of the instruction. The presentation of the results, the reflection and the suggestions for further research are included in the sixth section called discussion.

2 Description of the Research Place and of the Study Environment

The coeducational school of Orivesi has served as a primary study environment for seven years. In this comprehensive school, in which there are over three hundred pupils, higher classes (7th-9th) are taught. My colleague Sauli Hartikainen and I have been responsible for the designing and carrying out of the project. We have done the developing of the system in addition to our own profession as teachers. It has to be seen as a process of our own voluntary vocational lifelong learning. The project money has made short full-time periods of development possible. The cooperation with the University of Tampere began when I remained in the autumn of 2010 for two years to the study leave. As its consequence, we have got student resources from university during three school years for the building the learning environment. With the help of the project money, we have also been able to get graphics and graphic design. We began to partially use the learning environment immediately since the autumn term in 2006. When we were able to use the computer class since the autumn term 2009, we began to use the learning environment in the teaching full-time. By the year 2013 the number of the teaching groups has increased to eight. The number of the computers has restricted the use of the learning environment.

3 Description of the Study Process in Chronological Order

The developing of the learning environment during the years 2006 –2013 is described as seven school year long cycles in this section. The cycles are described as rounds of five different stages using Susman's and Evered's model [23]. The first cycle is described in the subsection 3.1 and the latest, in other words seventh, in the subsection 3.7. Cycles from the second to the sixth are described in the subsections which stay in-between.

Susman and Evered define the cycle of action research having five phases: diagnosing, action planning, action taking, evaluating and specifying learning. Diagnosing means identifying or defining a problem, action planning means considering the alternative courses of action for solving a problem, action taking

means selecting a course of action, evaluating signifies studying the consequences of an action and specifying learning signifies identifying general findings.

The first four cycles of the study process were stages in which case I implemented the system myself. In the rest three cycles the programming work has been done in the project work course of the University of Tampere while I and my colleague have been clients. However, when I studied software engineering at the University of Tampere for two years, I acted in the first project in the project worker's and customer's double role and in another project in the project manager's and the customer's double role. The project group has changed every year. The transition of the implicit information has been helped that at least one person as a project worker has continued in the following project as a project manager. The phases defined by Susman and Evered [23] appear more clearly in the latest cycles than in the earlier ones because of the project work courses. Scrum has been applied as a software development model and the software architecture started to base on MVC design pattern in the project work courses. Before the project work courses my programming did not follow any software development model nor design pattern. It can be described as the piloting programming of functionalities without clear aims for the filling of qualitative demands.

It should be mentioned that the artifact under development has been used beginning from the first cycle in the teaching. The evaluation is based on the experiences received by **us** in our **own** job as teachers. In our action research, we have both developed the system and acted as a teacher using the learning environment, which **we** have developed **ourselves**. Coghlan [25] and Lallé [26] have shown that the researcher can have a double role both as a researcher and as a worker (manager) of the organization. Thus, we can use our own experiences as teachers to evaluate the artifact justifiably. Later our two colleagues from the coeducational school of Orivesi have begun to use the learning environment in their teaching. In addition, teachers from the separate sites of Finland started to use the system during the time of the latest cycle, of the school year 2012-2013. This might correspond to the definition of the action research by Carr and Kemmis [27]. According to that definition while the action research project progresses the more people bind themselves for the improvement of practices.

3.1 The First Cycle: Spring 2006 and the School Year 2006-2007

Diagnosing

Based on a text book teaching and its non-satisfactory effectiveness I was depressed. The idea to utilize information technology and communication technique (ICT) had stewed already long in my mind. I find a note in my diary 12th August 2003: "Developing of the network teaching." When I with my colleague in the winter 2006 became conscious on the similar willingness to develop, we started to discover the utilizing opportunities of ICT in the teaching.

Action Planning

We started to design a virtual learning environment supposing that the human being is a self-steering system [28]. We try to use the teaching method where the studying would be led by the pupil herself or himself as much as possible and the learning environment would support this. We recorded preliminary specifications of the system in our project plan in April 2006.

We had three alternatives: 1) to start to develop the system drawing up ourselves and to take it into use or 2) to start to adapt a ready virtual learning environment as Moodle and to take it into use or 3) to continue the designing of the system without bringing it not yet into use.

Action Taking

We decided to start to develop the learning environment ourselves because we had some skills to implement the system. Furthermore, we wanted to learn drawing up of Web pages. We argued doing ourselves with the fact that with increased experiences and skills, we could carry out such features in the system just that we wanted. We implemented the website using HTML, PHP programming and the MySQL database. The choice of tools was based on the recommendation of my friend who knew programming better than I. He also helped with PHP and database in the getting to run at the beginning. The site was invested in a website hotel and with domain name matematiikka.net. We used the learning environment with the teaching groups especially assigned to us and under our control.

Evaluating

The pupils' spontaneous theory studying did not succeed.

The first version of our system acted as the learning environment but it could not be utilized in the studying in the way we wished. The use of computers was not possible the whole time. For more than three hundred pupil there was only one functioning computer class in the school.

Specifying learning

The theory of mathematics must be taught in one way or another.

3.2 The Second Cycle: Autumn Term 2007

Diagnosing

In the previous term, the inability or unwillingness of the pupils to find out themselves the theory of mathematics was observed a problem.

In order to go forward in the utilizing of the network, the studying with it should become regular. With the computer resources of the school it was not possible.

Action Planning

We changed our thinking towards the theory teaching in such a way that it would be given to the pupils in one way or another. In order to achieve the use of the network environment to become regular, we decided to require the pupils to check of assignments and to mark of training results to the learning environment at home. We would like to mention such a detail, that we were planning to implement the feature, which trains the learning of the multiplication table.

This year we were the corresponding teachers for the learning groups of the seventh grade. We were considering the use of the learning environment with those groups. The second alternative was to continue with the groups of ninth grade

Action Taking

We continued with the teaching groups of ninth grade, because we had ready-made contents for ninth grade but not for seventh one in the learning environment. The home working was carried out. First it was made sure from the guardian (parents), that it was opt for the pupils to use the Internet at home. We began to draw up educational videos in the course of the autumn. They were given to the pupils in DVD. A function which practises the multiplication table was implemented as an individual feature.

Evaluating

According to the pupils as well as the guardian (parents), the obligatory home working proved to be too loaded. At the end of the autumn term it was drifted to the situation that the use of the learning environment was given up for the rest of the school year. The situation was critical. Especially my colleague received such a feedback from a few supporters that was knocking out. His situation went worse, because he punctually wanted to check trainings and their evaluation in the network at home.

My colleague's wife used the system to practice the multiplication table in the remedial teaching of the lower classes of the comprehensive school successfully.

We received affirmative feedback about the educational videos from the pupils. We did not distribute videos at YouTube at that time yet. That was, because I considered that channel was inappropriate for pupils on those days.

Specifying learning

Home working in learning environment cannot be demanded, or it must not at least load a pupil more than obligatory working without the system.

It is worth placing the renewing of working methods when the pupils change the school.

It was learned from the practicing of the multiplication table, that the practice can be motivating even if the user interface had a modest appearance and functionally. The immediate feedback and opportunity to get better results rapidly were the most important.

3.3 The Third Cycle: the Spring Term 2007 and the School Year 2008-2009

Diagnosing

The pupils and their teachers experienced, that the working in the network at home was too binding and it had to be given up. The problem arose from this because there were no necessary devices at school.

Action Planning

There were two alternatives: to give up the use of the system or to continue with those resources which were available.

Action Taking

We decided to continue with the limited resources and we used the learning environment in the teaching of the groups of the seventh grade.

Evaluating

The termination of the previous iteration to the crisis might have discouraged our motivation but two points encouraged us. First of all the Finnish National Board of Education provided the support for the developing of the learning environment for two years. Second we met Mrs Tarja Korhonen, a lecturer from the city of Kouvola. And she used the learning environment during the time of the spring of 2007 getting mainly affirmative feedback from the pupils. This cycle, which lasted one and a half year, was the most modest stage from the point of view of the developing of the system even though it was the first block where we got pecuniary support to the work.

Specifying learning

The workmate gave power to continue.

The public support was important to us even though it was fairly small. The support made the participation in the educations possible and it was possible to cover material expenses. The fact that our work was appreciated may have been even more important.

It was worth offering a learning environment into use of other teacher. We received positive feedback and some more experiences

3.4 The Forth Cycle: the School Year 2009-2010

Diagnosing

There were a lot of ideas and plans but the own skills and time seemed to be too limited.

Action Planning

Our colleagues and my friend encouraged us to clarify whether it would be possible to get the learning environment as the student project of the Tampere University of Technology. Another alternative was to continue with our own resources.

The possibilities to use of the learning environment in the teaching improved significantly at school when we got the possibility to use the computer class full-timely with two teaching groups. We had to choose whether we continued with the groups, which started to use learning environment previous year (8th grade), or should we start with the groups, which just begin in the new school (7th grade).

Action Taking

It happened that our project was not chosen as the project work in Tampere University of Technology. There was a lot of project work available. The students were not interested in our subject. So we continued with our own resources. At this stage, we had carried out user management and a user interface utilising MediaWiki. I implemented the features of the learning environment connected with MediaWiki. We began the use of the learning environment with the pupils who have just changed the school, because we had earlier learnt that it will be easier to start new procedures with the pupils, who change the school.

Evaluating

This cycle was epoch-making. For the first time we began to use the learning environment so that the teaching with the learning environment was continued with the same teaching groups until the end of the comprehensive school.

In the spring of 2010, I decided to begin studies in computer sciences in the University of Tampere since the following autumn. I experienced an educational work and simultaneous developing heavy. Furthermore, I wanted to improve my skills of software engineering.

Specifying learning

Even though the port of the technical university closed, a new port opened with my studies.

3.5 The Fifth Cycle: the School Year 2010-2011

Diagnosing

So far, I had not followed any software architecture when I had implemented an information system and its security was bad. I became conscious of these in the project work course in the university.

Action Planning

The system made by me served as the example. The task of the project team was to draw up the system following good programming style and having security. We had to choose a suitable software framework. The alternatives were, Joomla, CakePHP and CodeIgniter among others. They supported the MVC planning model.

Action Taking

We chose the CakePHP software framework eventually.

Evaluating

The new information processing system was brought into use in April. The old system was totally rejected, even the database was not saved. The access control of the learning environment remained unfinished.

The user interface remained modest, because the developer of the interface went abroad during the project. In any case, we were able to produce a considerably better system, especially qualitatively.

Specifying learning

The studying is worthwhile. Other studies besides the project work course were useful from the point of view of the developing of the learning environment.

The information technology know-how does not guarantee an ability to think of what is significant and important pedagogically. I noticed the importance of my teaching experience.

3.6 The Sixth Cycle: the School Year 2011-2012

Diagnosing

The access control had remained unfinished. Because of this the information security of the system was threatened. The user interface and the appearance were modest reducing the interest to use the system.

Action Planning

We hoped that the new project team would continue work.

Action Taking

The leader of the project work course accepted the subject and the developing continued. I operate in the project group in the project manager's and the customer's double role myself. We corrected the access control. We bought graphics and graphic design because we had project money. This way we made the appearance of the system to be more taken.

Evaluating

The second successful project by students strengthened the idea that the development work was worth continuing as student work.

In his study, Topi Anjala noticed that the attitudes of the pupils who study on the learning environment were more positive than those of the pupils of control groups.

The instability of the site appeared soon after the updating of the system.

The second negative point was that the Geogebra applets that were used in the system, did not function.

Specifying learning

The appearance has significance. When we demonstrated the system which had got a new appearance to the persons who knew the system before, they were excited about the reform.

3.7 The Seventh Cycle: the School Year 2012-2013

Diagnosing

The previous updating caused the instability. It was uncovered that the reason was in the drills which I had carried out ineffectively.

Because of the information security problems of Java the Java support was removed from a pupil network. Thus the Geogebra applets did not function any more.

The automatic controlling of the studying and the giving of the feedback still did not fill our wishes.

The reports received by the teacher were unfinished still.

Action Planning

Again, we hoped that the new project team would continue work.

Action Taking

The third project work in the university came true. At the moment of the writing of this article, we are waiting for the updating, where it will be reacted to all the drawbacks mentioned before. The project team proposed the updating of the CakePHP software framework from version 1.3 to version 2.0. We accepted the proposal.

Evaluating

The teachers have begun to use the learning environment around Finland even though the learning environment has not still been actively marketed. The teachers who are interested in the use have made the connection by e-mail in order to ask for the teacher's rights to their account. Many teachers are from the school where another teacher has used the system already earlier. We consider this snowball effect affirmative.

Topi Anjala [29] studied the pupils' view on mathematics. The results were more affirmative in all the variables in the groups who used the learning environment than in the control groups. The material had been collected during the previous cycle.

The maintenance of the virtual server and the background software - e.g. Apache, MySQL, PHP - requires special know-how.

Specifying learning

The maintenance of the system is worth outsourcing so that we can concentrate on the essential.

4 Lessons learned

In this section, we list the planning principles for the developing of the learning environment for the differentiated instruction in the comprehensive school. These principles appeared in the phases of "Specifying learning" in Susman and Evered - cycles [23]. Schön [30] has studied this kind of reflecting of the employer's own working methods in order to improve them.

1. The theory must be taught in one or another way (Sub section (Ss) 3.1).
2. A pupil cannot be required to use the information processing system at home. At least, it must not load a pupil any more than working without the system (Ss 3.2).
3. It is worth placing the changing of the working methods when the pupils change their school (Ss 3.2).
4. In the features to practice the routines, like the multiplication table, the immediate feedback and possibility to improve fast the results are the most important things. Even the modest user interface and appearance are not restricting factors (Ss 3.2).
5. When the difficulties arise in the development work, the workmate is more important. This showed up when the parents resisted the use of the system and we had to give up for the rest of the season (Ss 3.3).
6. The relatively small external support can encourage when the motivated teachers develop the system in order to improve teaching. The first support which we got from the Finnish National Board of Education was quite small. The fact that our work was appreciated was important to us (Ss 3.3).
7. The system which seems modest and unfinished is worth giving an outsider to be tested (Ss 3.3).
8. When one door closes, another can open is true in developing too. Our work was not accepted in the Tampere University of Technology 2009, but next year I started my studies in the University of Tampere and our work was accepted as a project work there (Ss 3.4).
9. Having the information technology know-how does not guarantee person's ability to understand what is significant and important pedagogically. The pedagogic know-how is necessary in the planning of the information processing system that has been meant for studying. This finding we have found in each project work in the University of Tampere (Ss 3.5, Ss 3.6, Ss 3.7).
10. The appearance of the system has significance when the support is asked for development (Ss 3.6).
11. The maintenance of the system is worth outsourcing so that the people responsible for the planning can concentrate on work more essential one (Ss 3.7).

5 How Does the Artifact Meet the Requirements of the Differentiation

Tomlinson et al. [14] have defined the requirements of the differentiation by marking off what the differentiation *is not* and what *it is* and by giving a more exact *explanation*. In the following list some requirements are examined from the point of view of the learning environment (*math.fi*):

1. *It is not*: Just for students with labels. *It is*: For every student. *Explanation*: Every student has particular interests and learning preferences as well as a readiness level that varies over time and situation. Each learner needs appropriate support. *Math.fi*: Every pupil practices his own individual tasks in his own rhythm.
2. *It is not*: Something extra in the curriculum. *It is*: At the core of effective planning. *Explanation*: Differentiation is not something you do when the real lesson is finished. It's integral to the whole taught and it tries to guarantee that each student has a path to success with key content goals. *Math.fi*: The learning environment is particularly for this purpose.
3. *It is not*: Tracking in the regular classroom. *It is*: The antithesis of tracking. *Explanation*: Effective differentiation requires use of flexible grouping patterns so that students consistently work in a variety of groups based on readiness, interest, learning preference, random assignment, teacher choice, and student choice. *Math.fi*: The working is based on the pupil's choices which are supported by the automatic supervision and feedback system that has been built in the information processing system. Also a spontaneous peer support seemed to show up as functioning.
4. *It is not*: Synonymous with student choice. *It is*: A balance between teacher choice and student choice. *Explanation*: There are times when it's important for teachers to assign particular works to students because it will move them forward in the key direction. Otherwise, it makes good sense for students to call the shots and learn about making wise choices. *Math.fi*: The pupil makes her or his own choices in the learning environment. However, the automatic feedback given by the learning environment is directing the pupil into the essential direction. The teacher can intervene in the pupil's action when seeing in real time what kind of notes the pupil records into a system.
5. *It is not*: Individualization. *It is*: Focused on individuals, small groups, and the class as a whole. *Explanation*: Although an aim of differentiation is to focus on individuals, it is not a goal to make individual lesson plans for each student. *Math.fi*: In this, we disagree with because in our opinion, it is meaningful in the mathematics that the pupil practices tasks suitable particularly for her or him at each moment.

The learning environment fulfills the criteria of the differentiated instruction according to Tomlinson et al. [14].

6 Discussion

The quality of the action research is measured with its usefulness [16, 17]. The usefulness is shown with four indicators. First of all, the learning environment fulfills the criteria of the differentiated instruction according to Tomlinson et al. [14]. Second, my own use and my desire to develop the system support its usefulness. Third, several teachers have begun to use the system during the last year and their desire to use the system demonstrate its usefulness. Fourth, affirmative feedback that has been received from the pupils and Anjala's [29] studies about the pupils' positive view on mathematics show that the system is useful. Furthermore, the knowledge has been produced for the developing and use of the system. It was described in Section 4.

After different stages we have proved to be possible to build the artifact which supports the differentiation of the instruction and is already widely in use. According to Gregor and Hevner [31] the acquired contribution can be classified to level two. Gregor and Hevner talk about the design science research (DSR). However, we invoke to the study of Järvinen [21] where he shows that action research is similar to DSR.

In the future, a more comprehensive literature review has to be made. Second, a study on the effectiveness is needed even if the system were considered useful [16, 17]. Measurement of effectiveness in learning must be conducted as a controlled experiment concerning both the teachers and the pupils. The third subject of the further study is a theory from the human being as a self-steering system [28] which will get implicit support when the pupils accept a system built on the basis of that theory. Finally, it is necessary also to specify the method of the action research in which the actor of the organisation is a researcher himself [24, 25].

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